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INITIAL PROCESSING OF SPACE SHUTTLE CLOUD PHOTOGRAPHS

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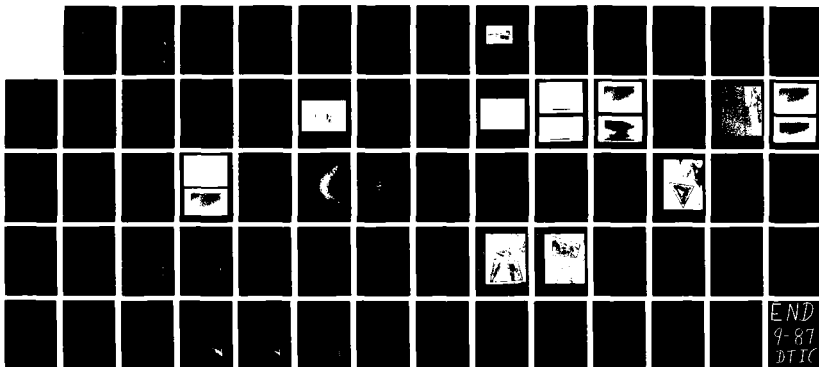
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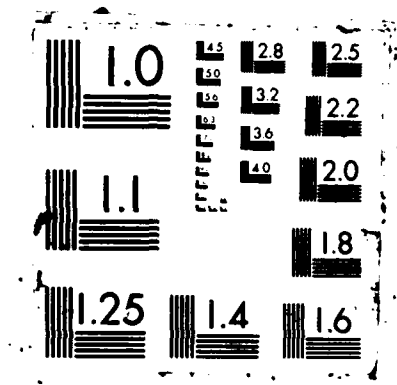
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Initial Processing of Space Shuttle Cloud Photographs. *PHASE 1.*

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Chase
Consulting

28 March 1987

Final Report
August 1986-February 1987

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3. Apply a statistical cloud classification technique to assess the cloud amount and the spatial variability of the cloud fields.

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ABSTRACT

In this report techniques are described for the computer analysis of the series of photographs of specific cloud scenes taken from the orbiting space shuttle. A method for extracting high resolution navigational information from the space shuttle hand-held camera imagery has been developed. Also, methods are applied which differentiate cloudy from clear areas with both ocean and land backgrounds and over a wide range of viewing geometries.

Three specific objectives are achieved:

1. Develop and implement high resolution digitization of the photographic transparencies so they can be automatically processed by the computer.
2. Develop and implement rectification techniques that will provide angle from nadir, geographical and scale information that can be associated with each feature on the transparencies.
3. Apply a statistical cloud classification technique to assess the amount and the spatial variability of the cloud fields.

This work should be carried forward in Phase II to produce a fully operational methodology to enable the benefits of this research to be realized in a real-time assessment environment. Cloud properties studies can provide a potentially valuable new tool for improving weather prediction and meteorological assessment studies.

ACKNOWLEDEMENT

The series of the cloud photographs analysed were taken aboard the "Discovery" shuttle during mission 51-C as a part of the U.S. Air Force sponsored space shuttle experiment entitled CLOUDS. We thank the commander and crew of this mission especially astronaut Gary E. Payton for producing these excellent photographic series.



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Introduction

The basic demonstration made in the work reported on here is the increase in value and utility of cloud data extracted from the monochrome transparencies taken by crew members of the space shuttle with a hand-held camera. (Details on camera, lens, film, etc. are contained in Snow and Tomlinson, 1987- Reference [1]) Numerous photographs taken during space shuttle missions in 1984 and 1985 have been digitized and rectified. Also, a proof-of-concept study to demonstrate the feasibility of using a statistical cloud classification method to assess the amount and spatial variability of cloud fields have been completed.

The fact that space shuttle photographs were taken with the high resolution film, which results in high resolution digital images, has been exploited in the analysis. Three specific technical objectives which have been completed are reported on:

1. Develop and implement high resolution digitization of the photographic transparencies so they can be automatically processed by the computer.
2. Develop and implement rectification techniques that will provide angle from nadir, geographical and scale information that can be associated with each feature on the transparencies.
3. Apply a statistical cloud classification technique to assess the amount and the spatial variability of the cloud fields.

Major Results

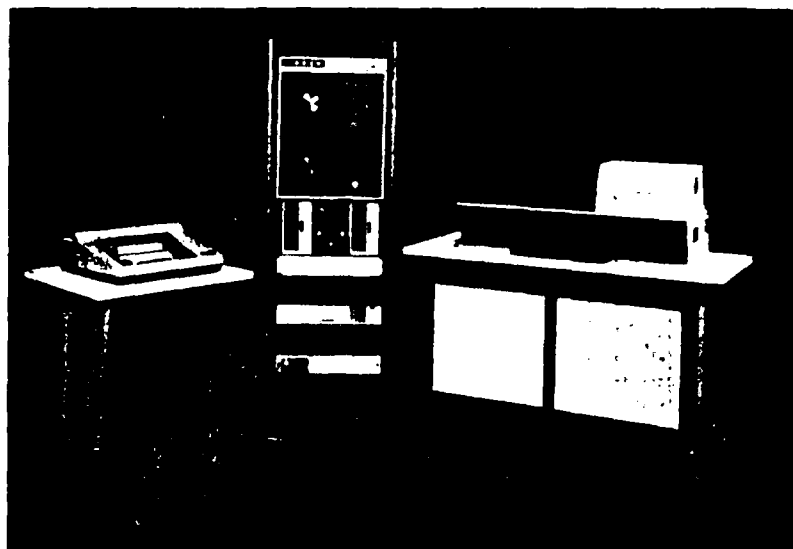
These objectives have been pursued using series of images of cloud fields taken with a 35mm camera aboard the space shuttle "Discovery". The results are illustrated in the main body of the report using the series of photographs taken offshore of Cape Canaveral, Florida. In Appendix A and B results for the other series are presented. Information on the location of each series is here given.

Location	Approx. latitude (°N)	Area Analyzed (sq km)	Underlying Surface	Month /Year	Local Solar Time
Cape Canaveral, Florida	28	7000	offshore	01/85	mid-afternoon
Maui, Hawaii	21	1300	land	01/85	late-forenoon
Gran Canaria, Canary Isls	28	1400	land	01/85	mid-afternoon
Gran Canaria, Canary Isls	28	2400	offshore	01/85	mid-afternoon

Digitization

The initial step was to select from each series approximately 20 images from the 35mm positive contact transparencies provided (see Figure 1a) with the aid of large positive prints (see Figure 1b). For the best utilization of the data, each 35mm transparency was enlarged into a high resolution transparency to be used with Optronics P-1000 scanner (see Figure 1c).

Next the digitization of the black and white transparencies was carried out on an Optronics P-1000 scanner connected to the bus of a VAX-11/750. A brief description of the digitization technique used by Optronics scanner is provided in the Appendix C.



Picture of the Optronics drum scanner P-1000

The whole sequence of 20 images was scanned 3 times on an Optronics: first pass established the dynamic range of the data transparencies, thus finding the greatest common range of gray scale values; second pass performed digitization at 50 micron resolution and final third pass was using 25 micron resolution. The table below presents the results of the last two passes.

Original image is 113mm x 72mm film		
50 microns resolution	2260 x 1440 pixels	3.25 MByte image at 256 gray levels
25 microns resolution	4520 x 2880 pixels	13.02 MByte image at 256 gray levels

All of the steps in the process of digitization described above involve a degree of uncer-

tainty and error. Simply finding the best overall dynamic range of a group of transparencies involves a lengthy procedure of sampling and experimentation. The step involving the change from the analog signal of the laser beam to the sampled digital signal varies in allowed errors, depending on the resolution of the step, thus allowing for a trade-off. There are a number of choices to be made in the search for the best scanning strategy, e.g., the problem of scanning an image at too high resolution and coming up with the actual grains of the film instead of meaningful information. The goal of the present effort is achieved by scanning several sequences, but even more so a foundation for further work was laid as plans evolved for a knowledge-based system that will govern work with different sets of images and will help to determine automatically the most appropriate techniques and procedures.

Processing always began with 50 microns resolution data, due to the image size, though all final analysis was accomplished 25 micron resolution data. To obtain more compact images an adaptive filtering technique was implemented using 2×2 and 3×3 blocking (see Figure 2). The scan file for each image yields a run-length encoded file on the VAX computer. For the better visualization of the data, a histogram equalization algorithm was employed. Since the original range of the gray levels does not span the entire scale of 8-bits (0 to 255), contrast enhancement was performed. If an image G has N (in this case $N=256$) gray levels, let $h(n)$, for $n=1, \dots, 256$ be normalized histogram. Then define the cumulative histogram

$$H(n) = \sum_{i=0}^n h(i).$$

The adjustment rule is

$$G' = H(n) \times G, \text{ for } G = n$$

The example of the gray scale histogram before and after equalization is presented in Figure 3. As histograms demonstrate, all features of the original image are preserved. Equalization greatly enhances visual perception of data. The above technique was used due to uneven optical density of individual transparencies that comprised the sequence.

Navigation

In order to make full use of the digitized space shuttle cloud photographs, the exact geographical location of each point on the image and the exact scale of each picture element (pixel) must be known. Since all the photographs were taken from one of the space shuttle windows at some angle relative to nadir (see Figure 4), they possess some degree of deformation relative to the map plane, which varies with position on the photograph. Thus, both the geographical location and the scale of each pixel must be computed from orbital and camera information. The first step is to determine the viewing geometry. The viewing geometry

available at the onset of the present work did not account for the lens of the camera and for an inherent distortion within an image. The above geometry was modified to account for the presence of a thin lens mechanism that more correctly reflects the physics of the camera used in the shuttle. The geometry and associate formulas for a thin lens are given in Figure 5.

At this point the navigation and rectification procedure begins. Since the exact position or the viewing angle of the camera is not known, the computations of the geographical and scale information therefore require some interactive work, whereby the viewing geometry at the time of the photograph is determined. Next is employed a software package, which Chase Consulting, Inc. developed over the last few years. The package named "PLANET" allows the computations and visualization of any field of parameter on a planet as viewed from an orbiting sensor. This software performs two important tasks:

1. Re-map on the sphere (or ellipsoid) a field of gridded data,
2. Computationally simulate the viewing of this field from space as a function of a position, viewing direction, lens, light sources, etc.

As an example, if the field displayed is the surface topography and we assume that there is no water over ocean floor surface, and under the following geometrical conditions:

- 1) Satellite (or platform) in equatorial orbit with subpoint ($90^{\circ}\text{W}, 0^{\circ}\text{N}$),
- 2) Sun at 45° (zenith and azimuth) from satellite location,

then the resulting visualization from the package PLANET is that presented in Figure 6.

Using the PLANET package, we can also re-map in spherical and viewing coordinates any coastline composed of a data set of points. The coastline values we had an access to, had the highest resolution of 3-5km, came from the SPSS package (see Figure 7a for the sample of the coastline of Florida). The data set for regions not in the SPSS coastline database, were generated by digitization from a large scale chart. One such example is given for Gran Canary Island in Figure 7b, with the data points taken from the high resolution nautical chart (the Gran Canary coastline is sketchy because only a few specific features of the distinctive coastline are needed and not necessarily an exact duplicate of the entire coastline).

PLANET system requires the following input to be present:

- a) Camera coordinates and directions:

CAMERA POSITION:	X,Y,Z
CAMERA DIRECTION:	X',Y',Z' - vector

CAMERA_UP_DIRECTION: X",Y",Z" - vector

b) Textures:

up to 3	TEXTURE_FILE:	name (on input)
up to 3	TEXTURE_SIZE:	X value,Y value
up to 3	TEXTURE_SPAN_LOW:	lat,lon (in degrees)
up to 3	TEXTURE_SPAN_HIGH:	lat,lon (in degrees)
up to 3	TEXTURE_POSITIVE:	range
up to 3	TEXTURE_NEGATIVE:	range
up to 3	PSCALE:	color_range (on output)
up to 3	NSCALE:	color_range (on output)
up to 3	BUMP_MAPPING:	yes/no
	BACKGROUND_COLOR:	value
	MISSING_VALUES_COLOR:	value

c) Lenses:

DISTANCE_TO_SCREEN:	value (in units)
SIZE OF SCREEN:	value (in units)
SCREEN_SIZE:	X value,Y value (pixels)
MATERIAL_CONST:	value (0. to 1.)
FOCAL_LENGTH:	value (in mm)

d) Reflectivity, directional and ambient lights:

up to 3	LIGHT_DIRECTION:	X,Y,Z - vector
up to 3	REFLECTION_COEF:	value (in percent)
	AMBIENT_LIGHT:	value (in percent)

e) Navigation:

LONGITUDE_AT_X_AXIS:	value (in degrees)
AUX_FILE:	name (output: long,lat)

f) Coast line and vector input:

COAST_FILE:	name (input or default)
COAST_TYPE:	value (1 to 3)
COAST_SCALE:	range (on output-color)

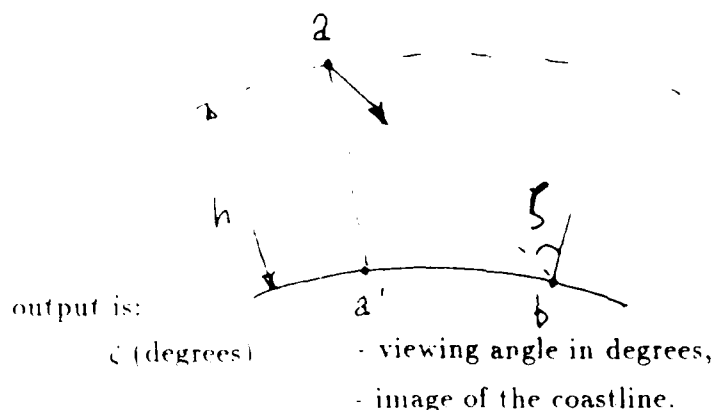
g) Animation option: MOVIE

(A more detailed manual of PLANET package can be provided upon request - Reference [3]).

As the result of the PLANET, an image for display and auxiliary files containing (lat,lon) pairs for each pixel of the image are generated. Now the task is to align the coastline produced by PLANET with the image of the coast seen on the shuttle image. This is done through the visual minimization for the verification: the various input parameters are iteratively modified until the best fit (about 1 pixel) is found. All computations end up accurate to .001 of 1 degree, or approximately .1km (100m) navigation (equivalent to 1 pixel). In order to speed the iterative process a pre-processor to PLANET has been developed in which:

inputs are:

- h (km) - first estimate of the orbit height,
- a' (lat,lon) - shuttle subpoint,
- b (lat,lon) - target (i.e. center of the image),
- s (degrees) - skewing of the camera (see Figure 4),



Once the coastline image is computed with PLANET from the set of best-guess parameters, it is displayed superimposed upon the original cloud image for assessment of the match. The difficulty is to assess which parameter to modify. To facilitate the choice a sequence of images are processed at once, with the same orbit altitude and other parameters. We stop at one-pixel accuracy, for examples see Figures 8a and 8b. To achieve such a precise match requires on average 25-30 trials. It is desirable to automate the above procedure, as it is not practical to spend such an amount of labor on navigation of a large set of images. The rules by which an interactive navigation procedure is governed are straight forward and therefore such navigation will be implemented in an AI (knowledge based) environment in the follow-on effort. The set of steps is presented below:

Mapping of computer generated coast lines with actual coast lines:

1. Input longitude and latitude of the center of an actual image.
2. Input altitude of the orbit.
3. Adjust parameters to achieve the proper focal length of the camera used (distortion

around the edges is monitored),

For Images Close to Nadir:

4. Adjust the camera-up position to correct for skewing. It is either clockwise or counter-clockwise, and the camera-up vector allows just such an adjustment.
5. May require adjusting altitude of the orbit for a proper fit.

For Oblique Images:

- 4'. All camera position are on the orbital sphere,
- 5'. If generated image is larger than required, then must move closer to nadir position. Here we use the size of the image for the selection criteria in the determination of oblique shots.
6. Movement parallel to the coast line will result in the skew adjustment. Here we use the geometry of the coastline to determine the skew adjustment.
7. If movement of the camera position to adjust skewing results in the improper size change then use camera-up to adjust skewing. Here we use the change of size of the feature on the surface to adjust skewing.
8. Adjust target longitude and latitude to offset the whole image.
9. Procedure takes about 25-30 iterations.

Using the above technique, the focal length of camera has been empirically obtained to be about 105mm. After a successful match the AUXILIARY file containing a (lat,lon) pair for each pixel of an image is produced. The process was repeated for each image of the sequence.

For the purposes of navigation and angle determination the entire sequence of images was processed from which the following table is compiled:

Cape Canaveral Offshore Sequence

300 km orbit

image #	camera		target		camera up vector			view angle (degrees)
	lat (N)	long (W)	lat (N)	long (W)	X	Y	Z	
2	28.35	80.42	28.350	80.425	0.0	1.0	0.18	3.44
3	28.35	80.35	28.357	80.455	0.0	1.0	0.21	3.72
4	28.30	79.76	28.335	80.515	0.0	1.0	0.08	14.72
5	28.30	79.52	28.335	80.511	0.0	1.0	0.07	18.98
6	28.29	79.11	28.320	80.481	0.0	1.0	0.05	25.37
7	28.30	78.66	28.320	80.470	0.0	1.0	0.05	32.09
8	28.30	78.19	28.310	80.500	0.0	1.0	0.03	38.76
9	28.31	77.62	28.300	80.500	0.0	1.0	0.00	45.20
10	28.32	77.38	28.290	80.460	0.0	1.0	0.01	47.20
12	28.36	76.51	28.250	80.480	0.0	1.0	0.00	51.80
14	28.46	75.43	28.190	80.600	0.0	1.0	0.00	62.28
16	28.65	74.64	28.130	80.850	0.0	1.0	0.00	67.10

Since from this table we can make a plot of the orbit subpoint sequence (see Figure 9), we can improve, if necessary, our previous results on the angles by constraining the sequence to be smooth. Then we can go back to our procedure and modify the appropriate parameters. Once the navigation auxiliary files are created for each image in the sequence we can proceed to the next step - the analysis of cloud coverage as a function of viewing angle.

Region Determination

Essential to the analysis is the selection of an optimum region. This means a region which has reasonably uniform cloud cover, appears in all images of the series, has good film quality (no scratches, etc.) and, at least for this first series to be analyzed, is not contaminated by a land background. For statistical significance the region should be as large as possible, in any case not smaller than 1000 sq km. Under these constraints the procedure is:

- a) choose points to form a closed polygon by hand on the original image closest to nadir, see Figure 10,
- b) compute using the AUXILIARY navigation files of PLANET the corresponding boundary points on the other images in the series, see Figure 11.

Cloud Analysis

The main step in the analysis is to distinguish the portions of each region which are clear from those covered by clouds. Several methods are possible, e.g. single-line gray level thresholding, gray level gradient thresholding or spatial homogeneity analysis. Although in principle any of these could be completely automated, at present each still requires interactive image processing. To better appreciate the problem single-line cross sections of gray levels are presented in Figure 12 and 13. The following features are noted:

- clouds (large gray values),
- sunglint effects (low-medium gray values: refer Figure 12, columns 232-240),
- cloud shadows (refer Figure 12, columns 209-211, 203-204)
- clear regions (refer Figure 12, columns 263-266)

By selecting particular subsets of the region being analyzed, certain of these features can be highlighted. In Figure 14a is shown a sunglint and in Figure 14b an example having only cloud and clear spaces over water is given. A simple threshold value determined from the raw information, such as Figure 12 would not be appropriate since it would either include the sunglint areas as cloud if it were too low or would exclude some clouds if too high. Therefore two other approaches have been investigated.

Gradient threshold technique

One approach to finding a threshold value is to utilize the gradient technique. A gradient image is made, Fig. 15. Assuming that cloud edge has a higher gradient value, an upper cumulative 10% of gradient values are taken and the mean and sigma values of the contributing pixels are found. Assuming Gaussian distribution of gray values and taking into account actual distribution of glint region in the images we take a threshold value to be the mean minus half of sigma (see Figure 16). The only limitation with this method is linked to the subjectivity of the choice of the gradient cut-off. In the present example it corresponds to a gradient value >60 , but as can be seen there are clouds which have smaller gradient values than that. It is anticipated that this method will slightly underestimate the cloud cover (about 2-5% underestimation). The results of this method, which were confirmed by the method next to be discussed, for the Cape Canaveral sequence are compiled below.

Results of Cloudiness vs Viewing Angle Study

Cape Canaveral Offshore Sequence

image #	gradient cutoff	mean gray level	sigma (σ)	mean-.5 σ gray level	percent cloudiness	angle in degrees
2	53=90.28	173	32.68	157	60.80	3.44
3	52=90.21	178	31.93	162	61.52	3.72
4	52=90.21	177	31.55	161	64.31	14.72
5	52=90.29	181	32.54	165	66.06	18.98
6	52=90.23	173	31.74	157	65.99	25.37
7	50=89.87	175	30.73	160	67.10	32.09
8	36=89.73	178	24.97	166	71.11	38.76
9	53=89.97	186	31.59	170	71.47	45.20
10	53=89.76	182	31.13	166	72.13	47.20
12	52=90.03	168	30.39	153	76.38	54.80
14	46=90.19	179	28.61	165	83.75	62.28
16	48=90.41	183	28.38	169	86.88	67.10

Horizontal homogeneity method

The second method we have investigated is the so-called horizontal homogeneity method of Coakley and Bretherton (Reference [2]). It was originally developed for AVHRR IR data, but we have re-applied it to the data provided from the space shuttle experiments.

We take the view here that the clouds are primarily observed as irregularly shaped and sometimes highly structured objects against a relatively uniform background. This view leads to what might be called operational definitions for the terms 'cloud cover', 'clear sky', and 'cloudy sky' over certain scale of pixels. The procedure for identifying the cloud cover layer is best described through example. Consider a 5 x 5 box of pixels taken from an original image. We will compute the mean and variance values for the box, and then moving such a

box in 1 pixel increments over an image we will obtain our Figures 17 and 18, for boxes 5×5 and 7×7 respectively (in Figures each point corresponds to a box of pixels).

Figures 17 and 18 show a structure that we will term an arch. Such arches turn out to be characteristic of local mean versus local standard deviation plots for the shuttle data. The cluster of low-variance points with low mean (left foot of an arch) is interpreted as representing the cloud-free scan spots, which in this case are clear regions over ocean. The cluster of low-variance points at the right foot of an arch is interpreted as representing the completely covered scan spots. We interpret the points in the body of the arch between the two clusters as representatives of partially filled fields of view. This interpretation appears to be reasonable in that we would not expect partially filled fields to exhibit sufficient local coherence or homogeneity to bring local variance as low as in cases of cloud-free or cloud-covered conditions. The limitation of this technique is that, in order to be identified as a cloud, image must be uniform over regions somewhat larger than a box (5×5). The high resolution of our data (2880×4520 pixels) allows us to have statistical significance in this method of analysis, and not miss any small clouds.

By looking at the thickness (or number) of boxes, that are below certain variance, we can both get an idea of the cloud size and cloud cover. Basically a mean value that is to the immediate right of the left arch foot is considered to be a cloud cover cutoff. Once this number is found, we can go back to the original image, and for each pixel, centering a box around it, we determine whether computed values are above the threshold or not. That makes our rule for cloud cover determination under a homogeneity method.

Plots for the cases of variance less than 5 and lower mean (i.e. left foot of an arch, which signifies the clear region) are given in Figures 19 and 20. Some of the interesting features can be found in similar plots for another series we have worked with. In Figures 46 and 47 we can identify three peaks present, which stand for: cloud shadow, clear, and sun-glint regions, in order of increasing mean.

An overall advantage of homogeneity approach is that we can get both cloud coverage and mean cloud size at the same time. The method itself can be easily extended to include some other simple statistics applicable to a certain box size, which is intended under Phase II effort.

Using the method described above we have performed the cloud coverage computations (and cloud size) and plotted that as a function of viewing angle (see Figure 19) for the Cape Canaveral sequence along with those discussed in Appendices A and B. The agreement between results obtained with the first and second method was impressively good - thresholds did not vary by more than .75 value on the gray scale.

The same complete analysis as described above has been performed on 3 more sequences. Complete set of results and supporting plots are in Appendices A and B for sequences of Maui and Gran Canary Islands respectively.

Future Work

Several refinements of the two approaches presented above in cloud analysis are possible. One which seems especially attractive is to improve the definition of the edge (the border between the cloud and shadow or background) by performing the analysis using overlapping boxes in the narrow strip or sub-domain which includes the edge. Recent publications on the subject of sub-pixel analysis also offer alternatives. The natural step for improving the spatial homogeneity technique is to include not only the mean and variance, but second and third statistical moments, entropy, minimum and maximum values in the box analysis. The precise knowledge of our position and image navigation also allows the computation of Sun position and thus locate any possible sunglint off the surface. The analysis can be refined by removing the sunglint from an image before the statistical cloud computations are done, based on the geometry and conditions of the surface.

The results presented above appear to be extremely promising with respect both to the feasibility of the proposed technique and to its potential value of information derived. The conclusion is that the original concept of digital analysis of these cloud images is indeed viable, and that proceeding to develop it to a practical technology is justified. The results have also pointed the way to a number of improvements and extensions.

Reference

- [1] Snow, J. W., E. M. Tomlinson, 1987: Cloud population measurements using photographs taken from the space shuttle, *Proceedings of the 6th Symposium on Meteorological Observations and Instrumentation*, American Meteorological Society, New Orleans, LA, pp. 286-289.
- [2] Coakley J. A., F. P. Bretherton, Cloud Cover From High-Resolution Scanner Data: Detecting and Allowing for Partially Filled Fields of View, *Journal of Geophysical Research*, vol. 87, no. C7, pp. 4917-4932, June 20, 1982.
- [3] Volfson L. B., Reference Manual for "PLANET" package, Chase Consulting, Inc., 1987.

Figure 1. Original Image Sequences

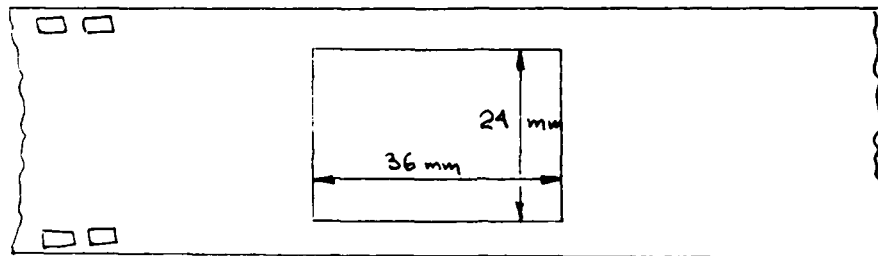


Figure 1a. Original Sheets

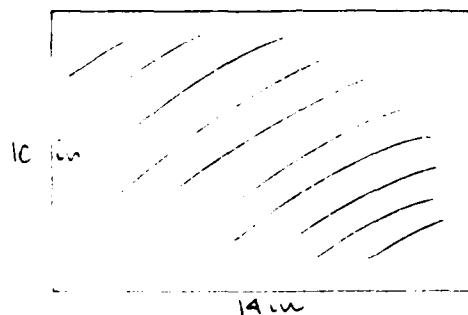


Figure 1b. Photographs

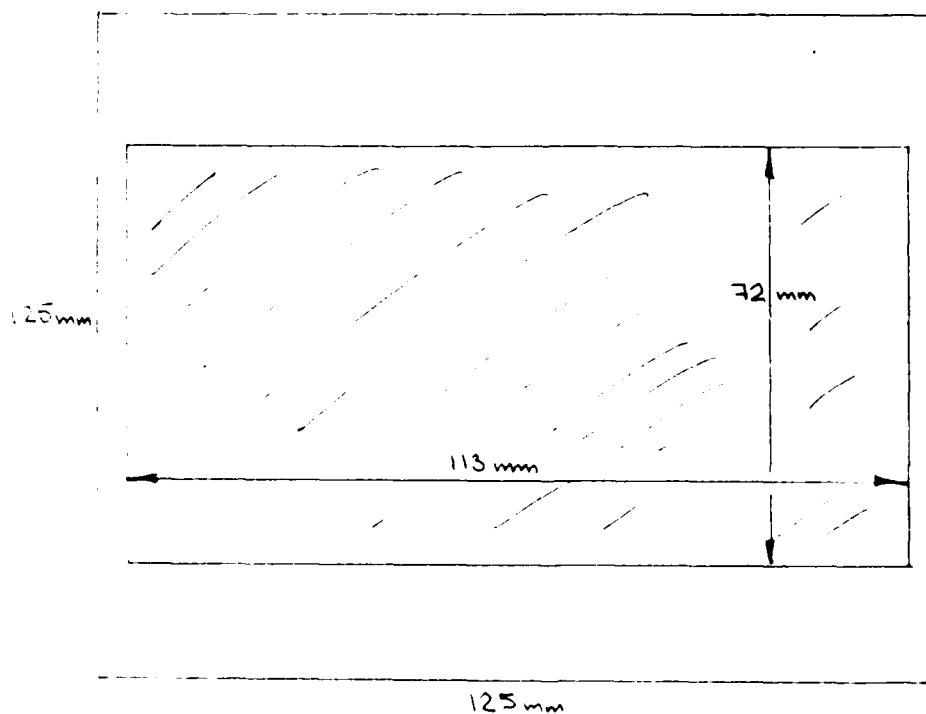


Figure 1c. Blow-ups for Optronics P-1000

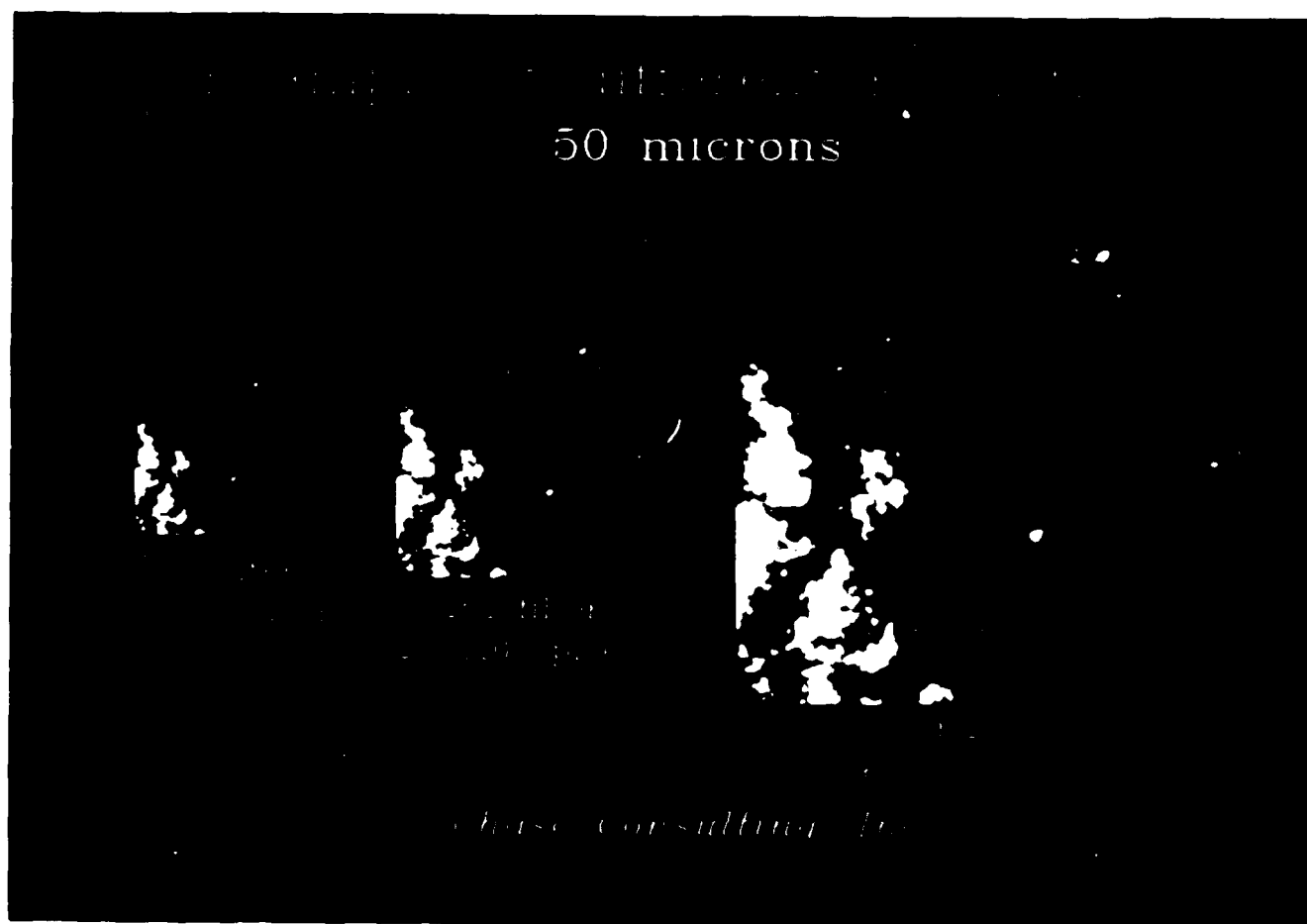
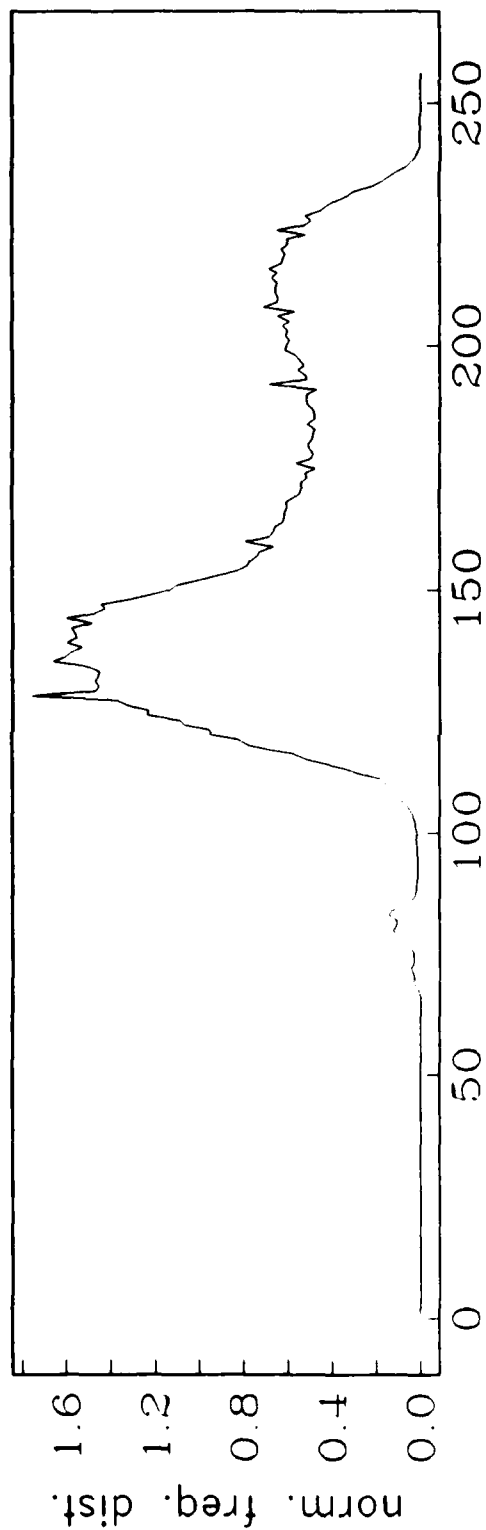


Figure 2 Example of different working resolutions

Histogram of Original Cape Canaveral No.2



Histogram of Equalized Cape Canaveral No.2

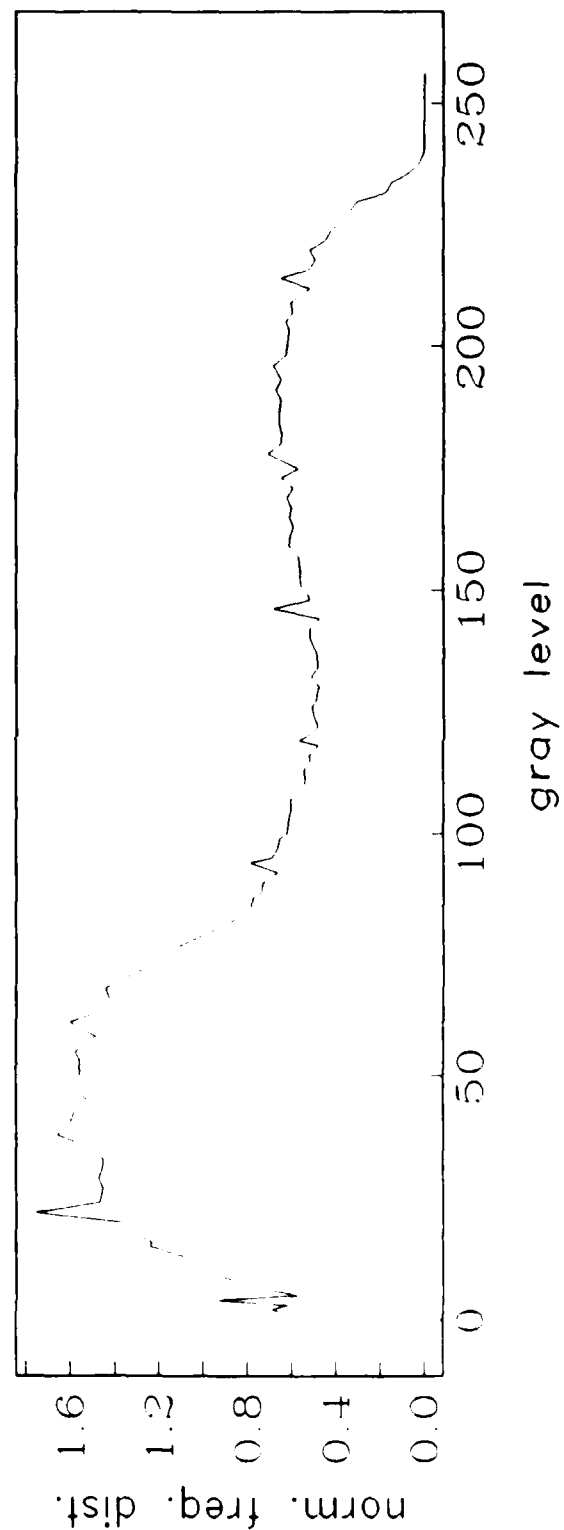


Figure 3 Histogram of the image before and after equalization

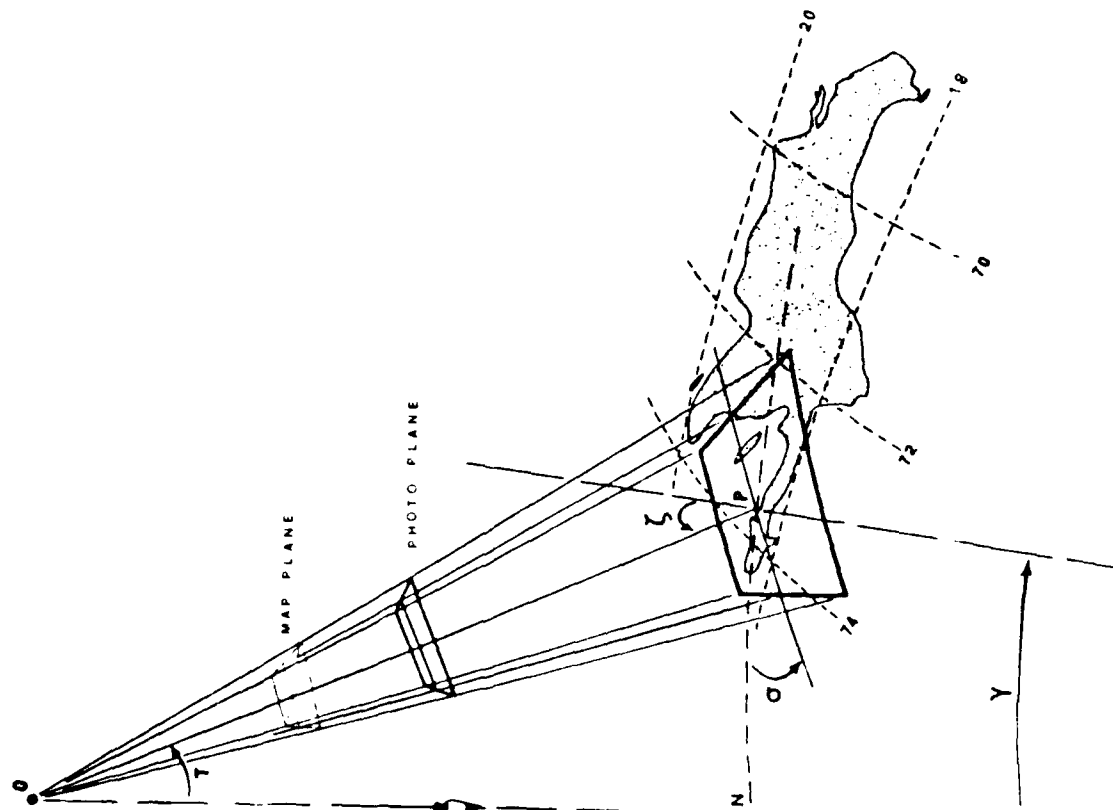


Figure 4 Originally provided viewing geometry

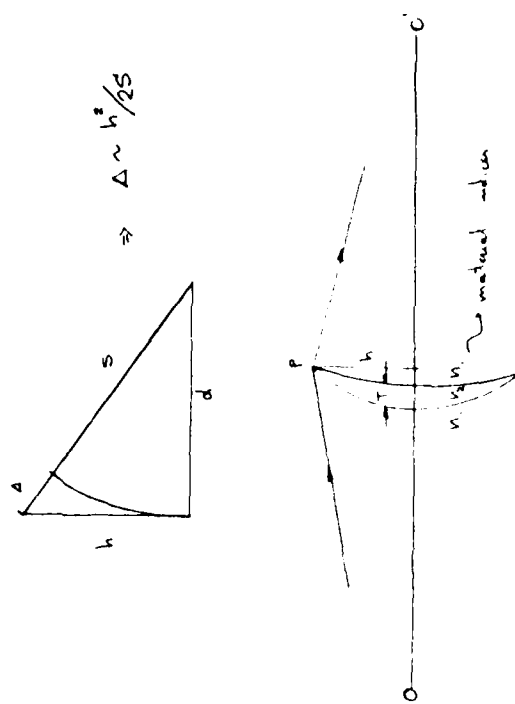


Figure 5a A thin lens with two positive radii

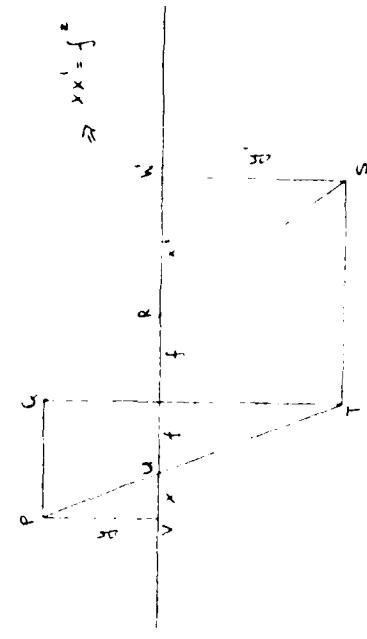


Figure 5b The geometry of imaging by a thin lens

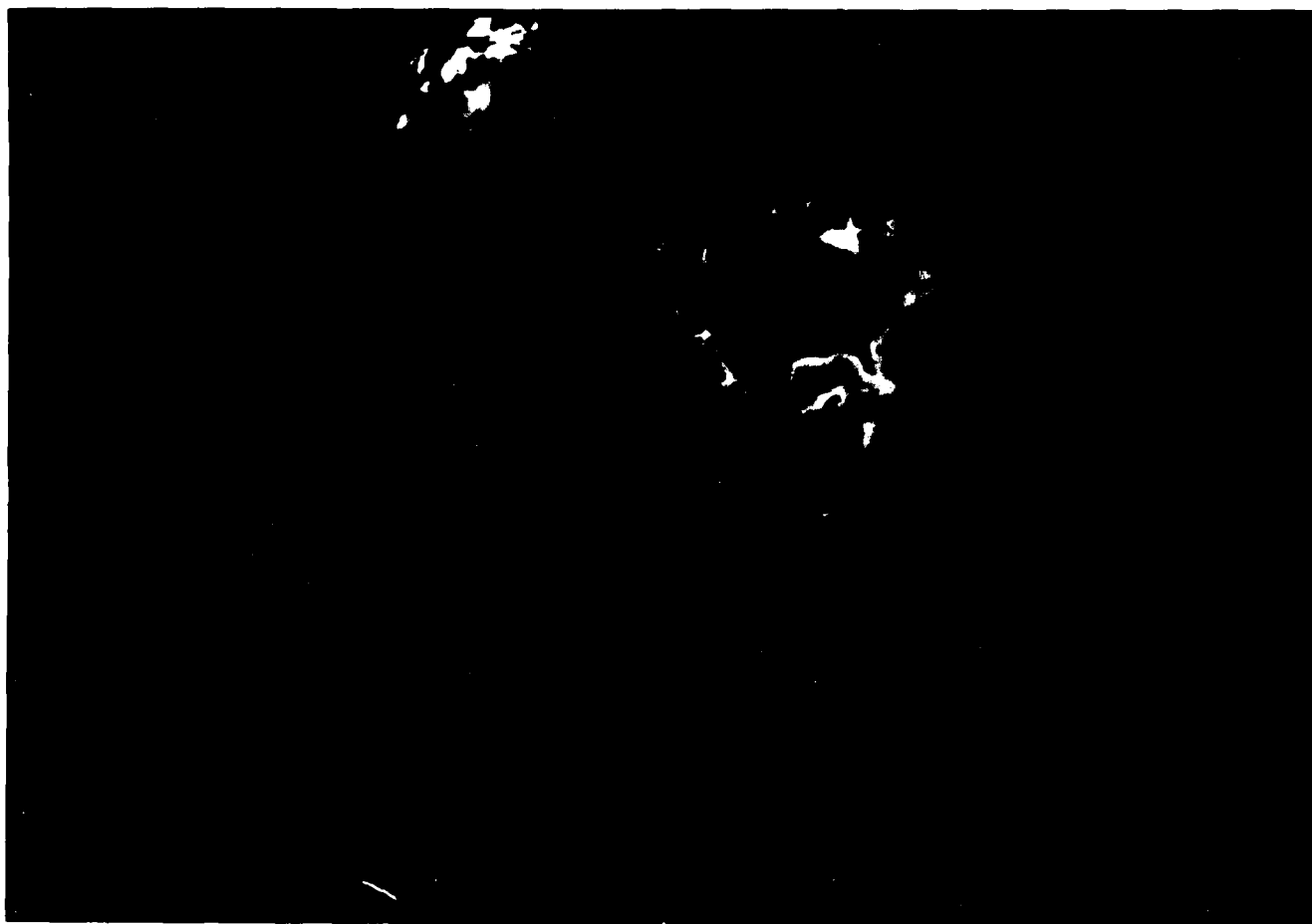
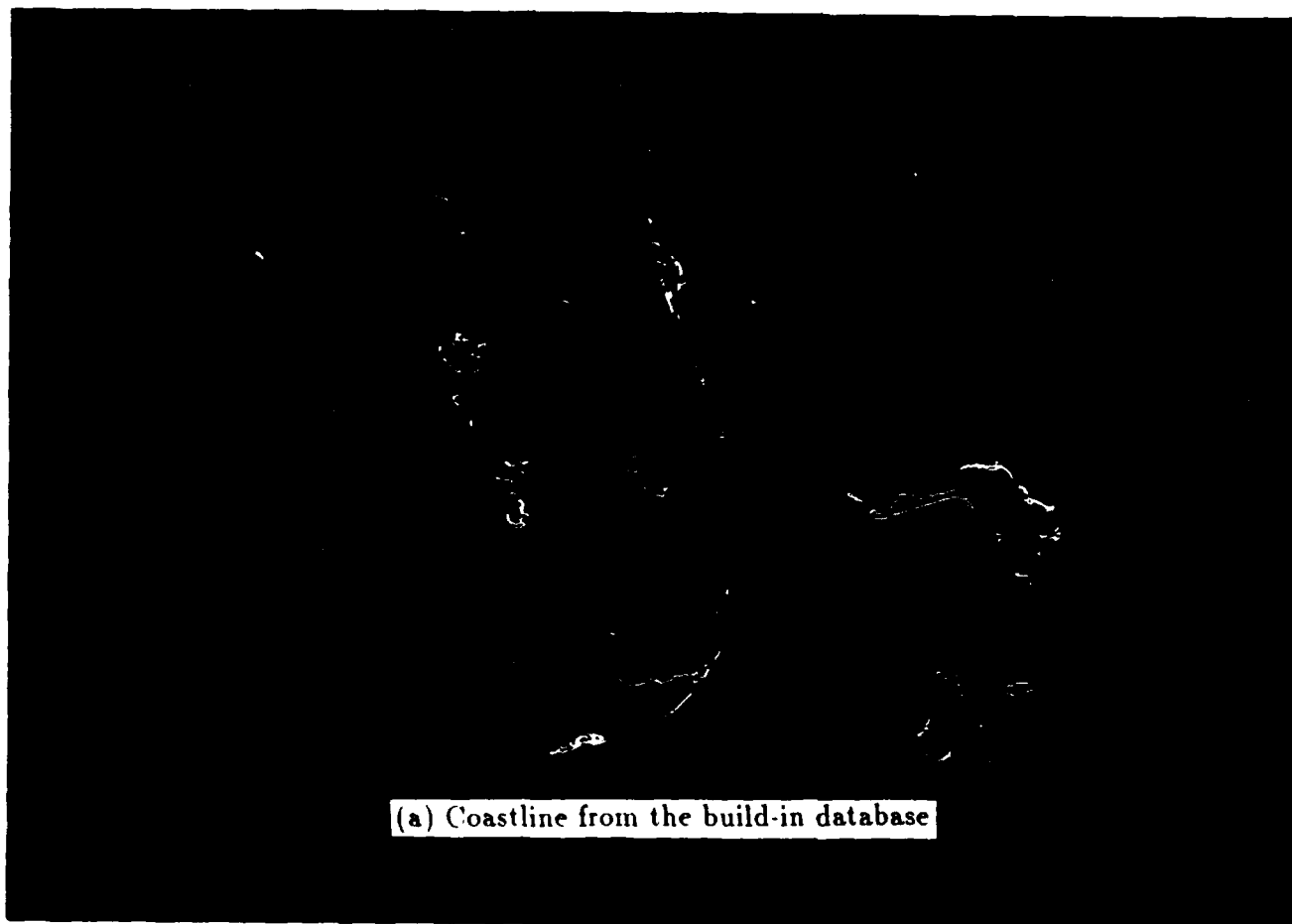
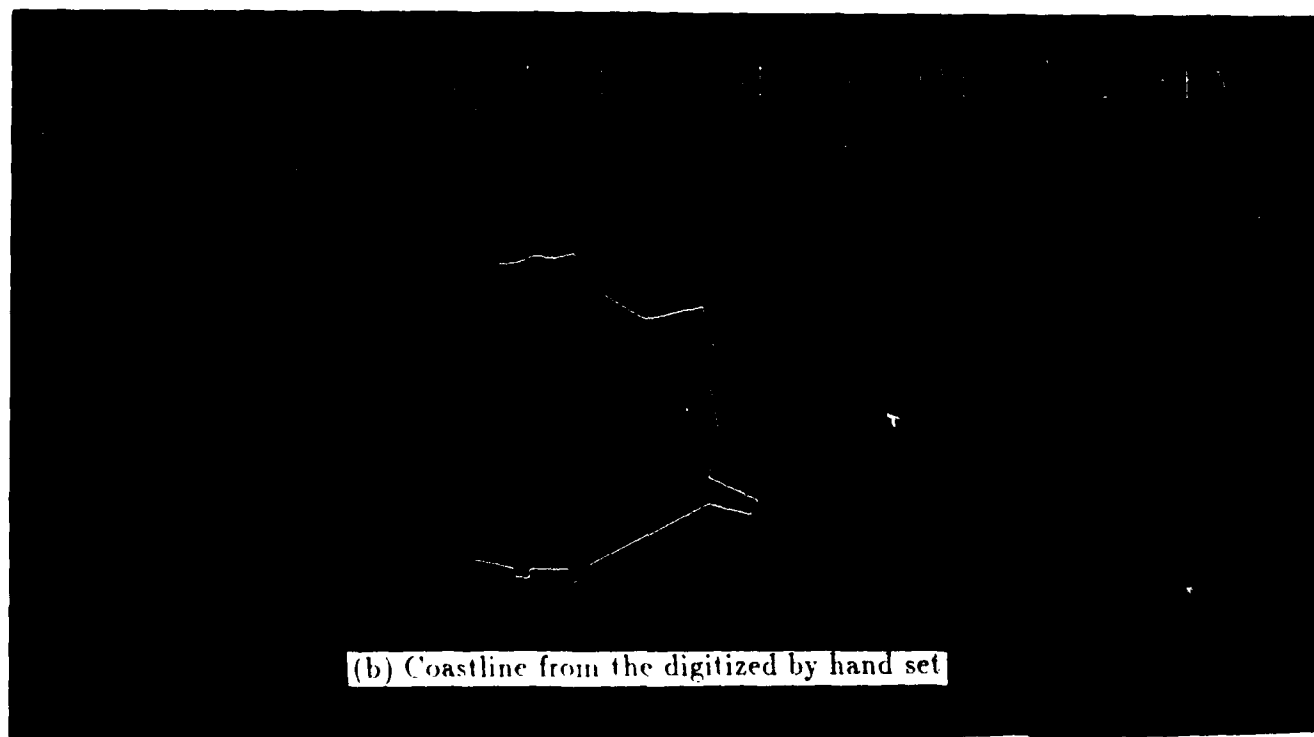


Figure 6 Example of PLANET package output



(a) Coastline from the build-in database



(b) Coastline from the digitized by hand set

Figure 7 Examples of PLANET package output of the coastlines

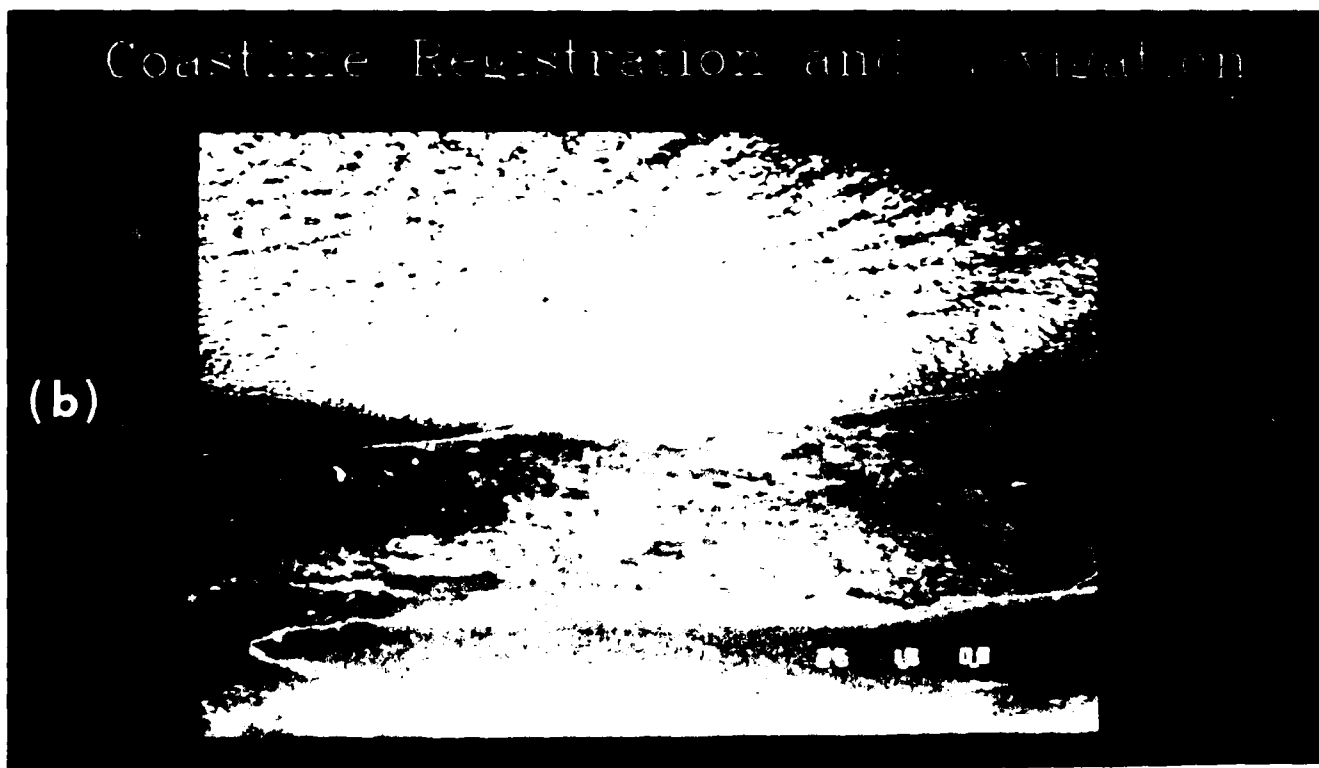
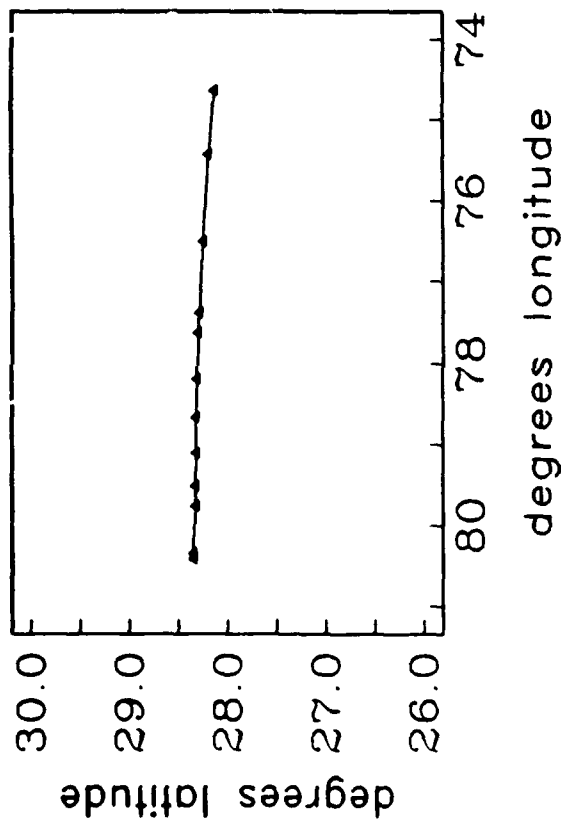
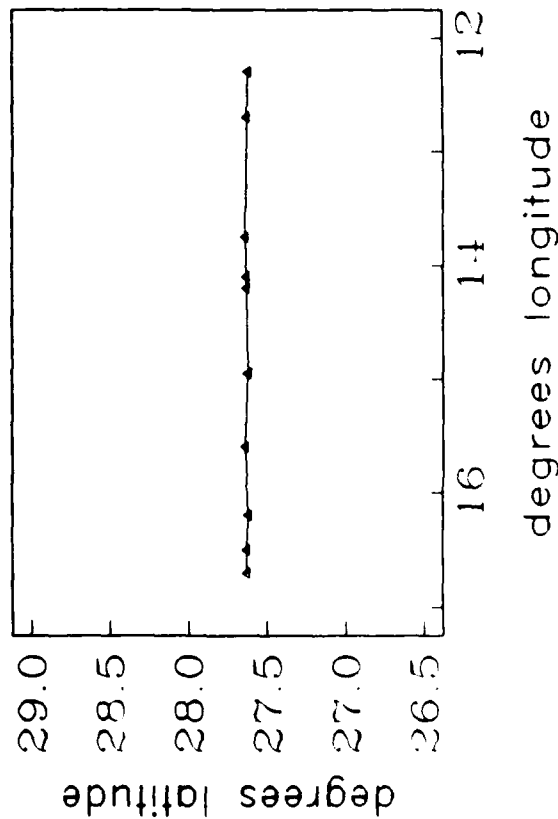


Figure 8 Examples of the coastline registration and navigation

Navigation over Cape Canaveral



Navigation over Gran Canary



Navigation over Maui

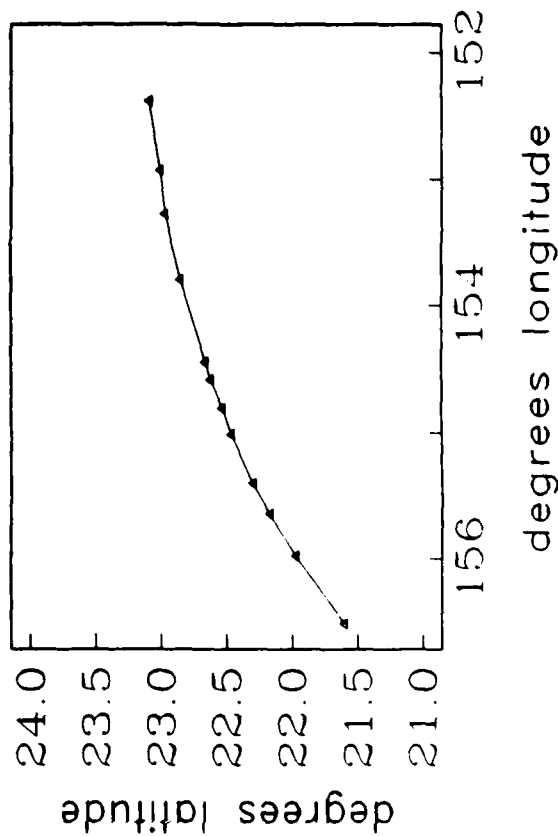


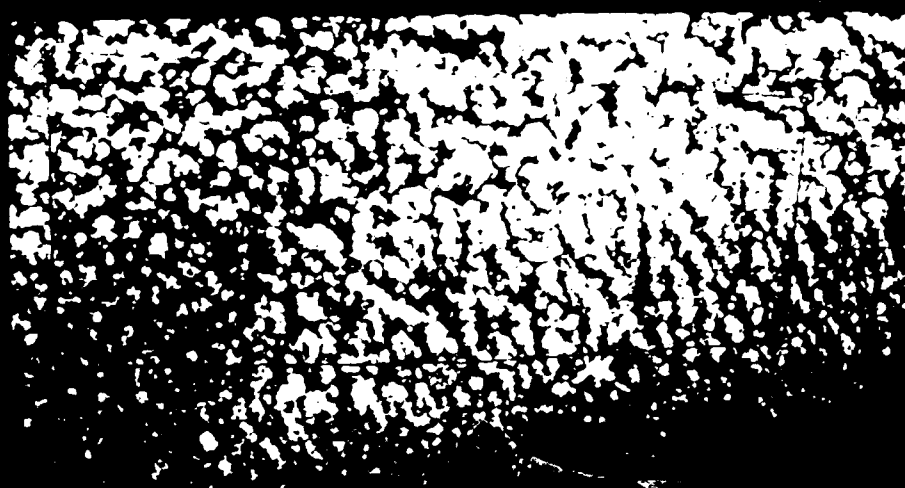
Figure 9 Results on navigation for all three passes



Figure 10 Region above the white line is taken for measurement

Region Determination on main image

(a)



26 19 06

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Region Determination on subsequent images

(b)



26 19 07

Figure 11 Example of the region determination of successive images

Gray Value Distribution - row 270 - Cape Canaveral No.3

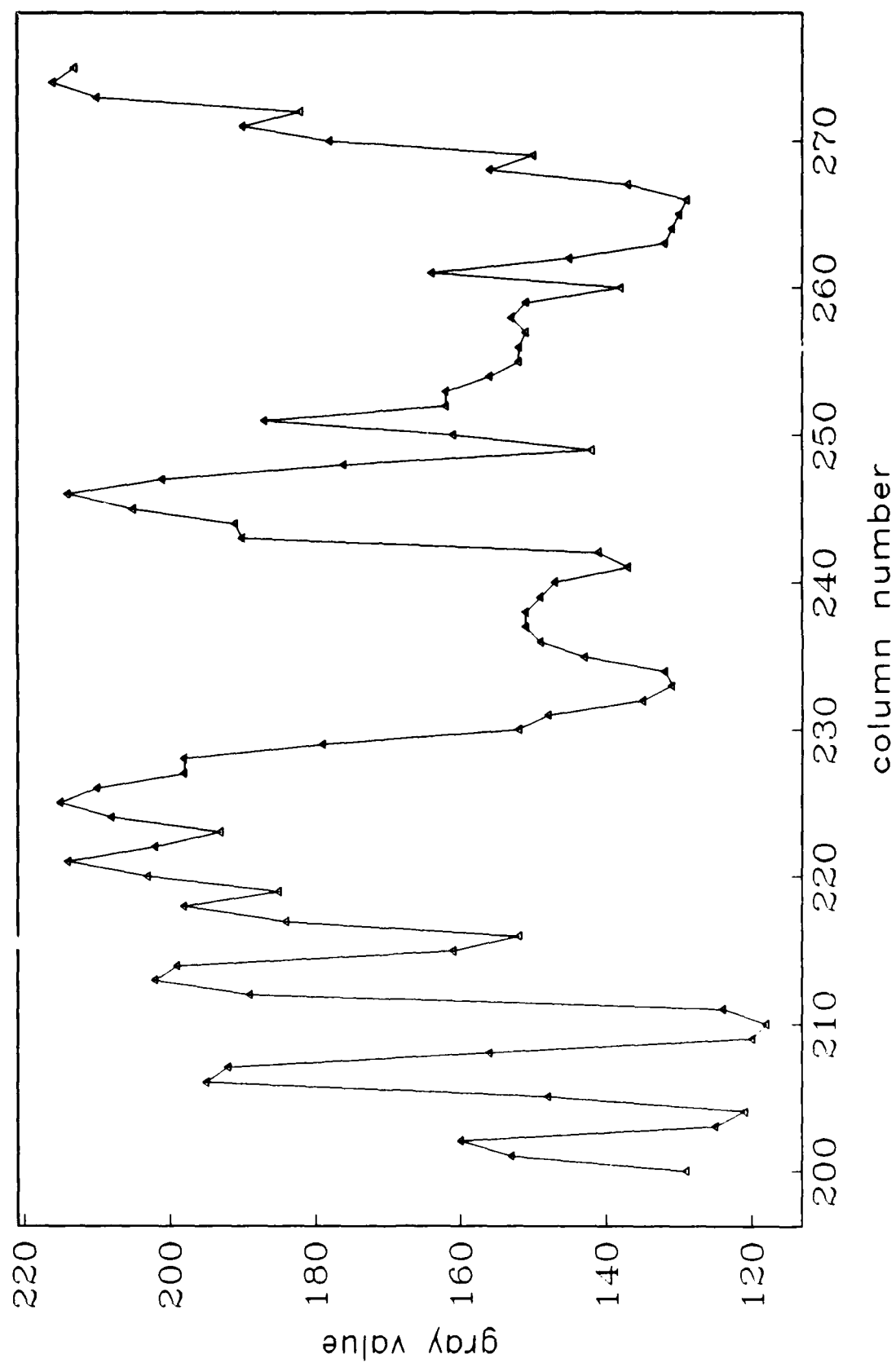
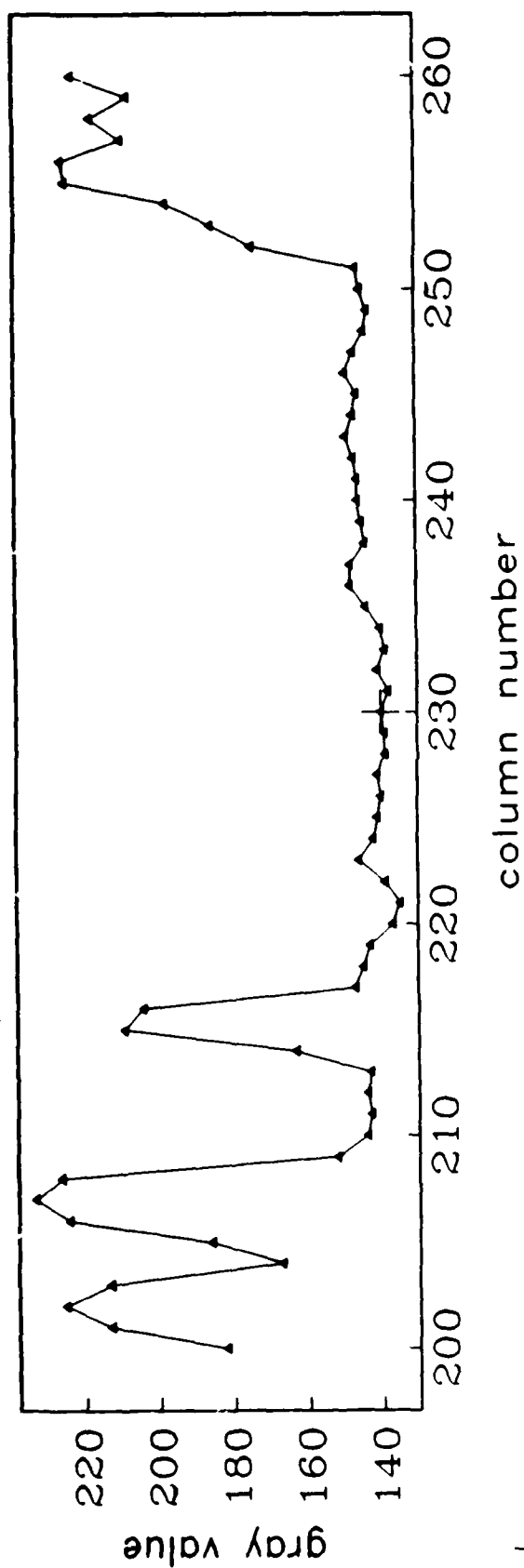


Figure 12 Example of gray value distribution in a sample image row

Cape Canaveral No.3

Gray Value Distribution - row 57



Gray Value Distribution - col 230

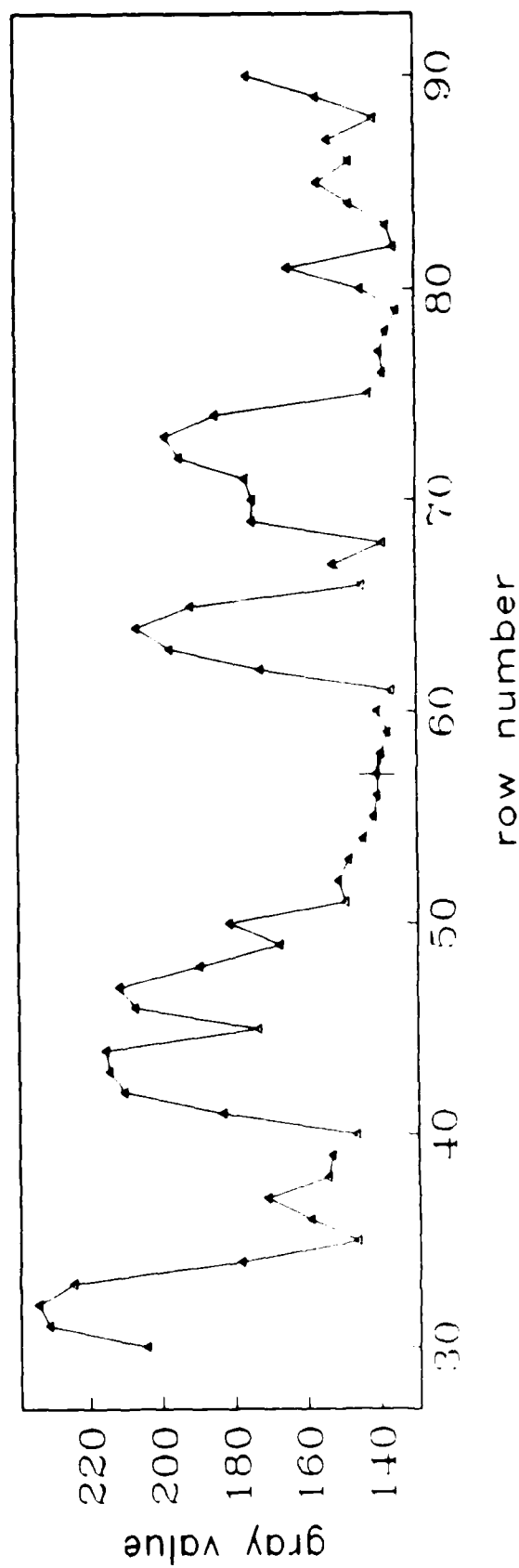
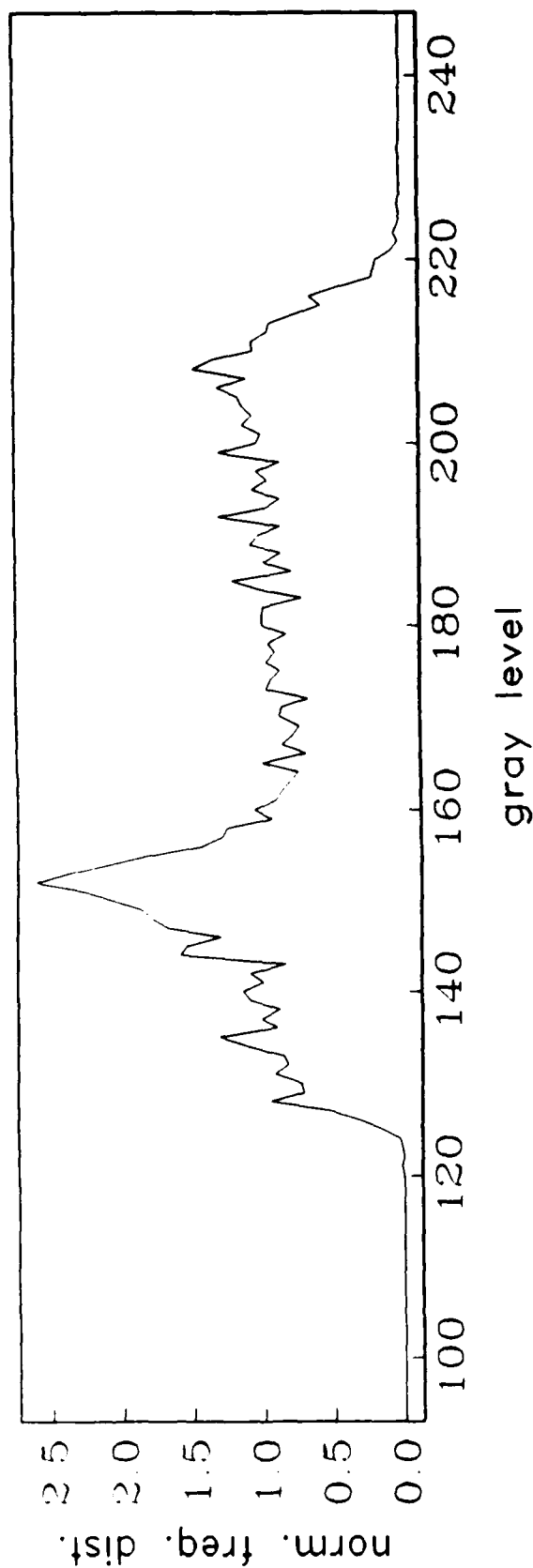


Figure 13 Example of gray value distribution in a row-column test

(a) Glint Region Histogram (240,265)(290,288) CC No. 2



(b) Cloud Region Histogram (10,35)(290,700) CC No. 2

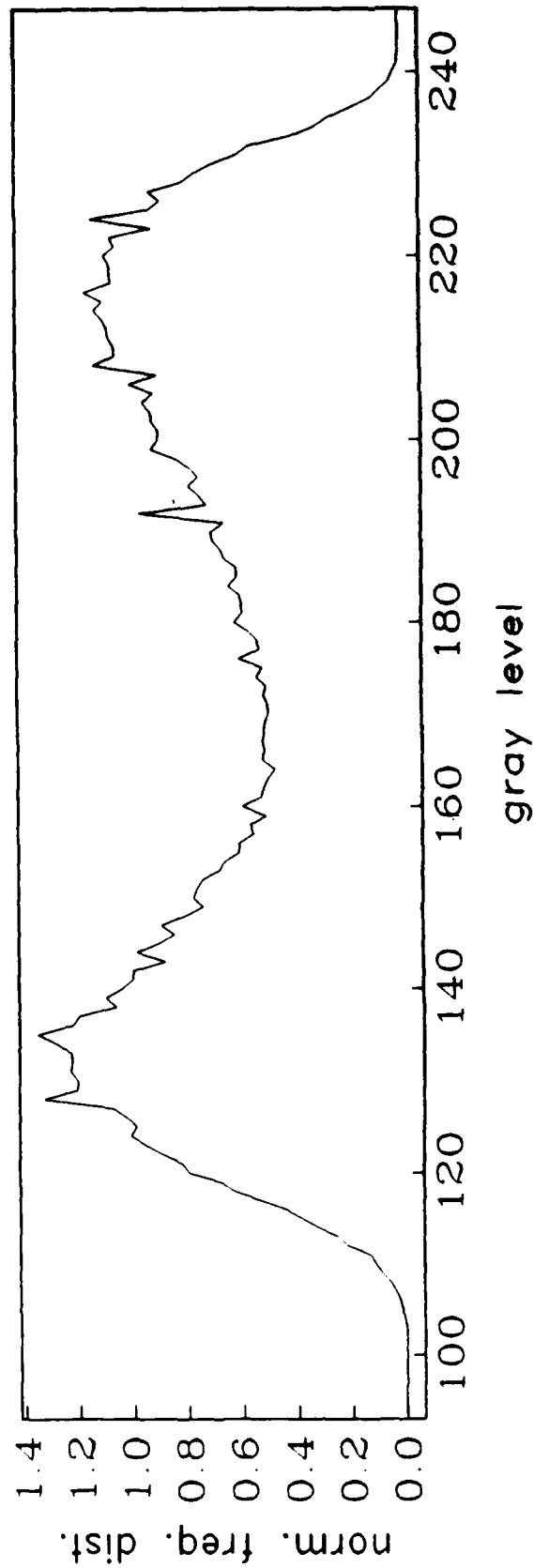
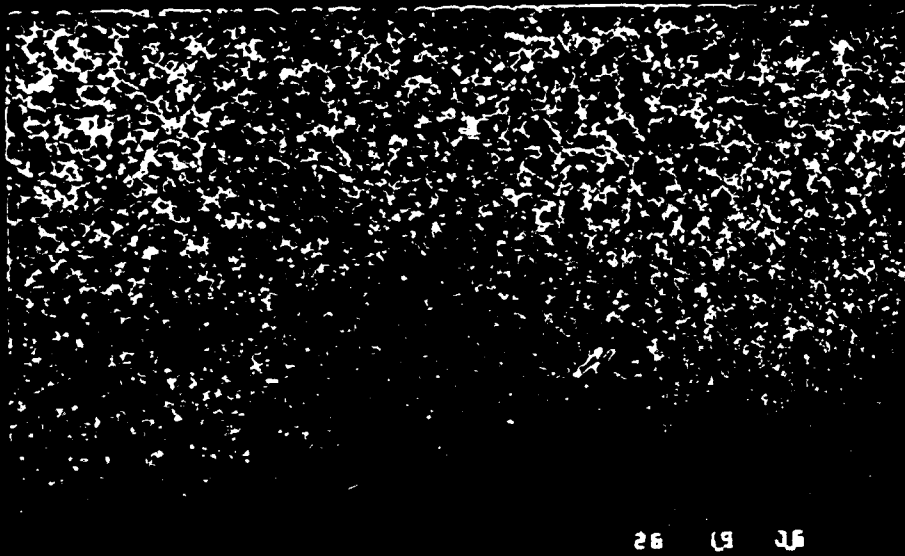


Figure 14 Cumulative histograms for glint and cloud regions

Gradient Image
Range from 0 to 130



Chase Consulting, Inc

Thresholding an image
cutoff at 157 level

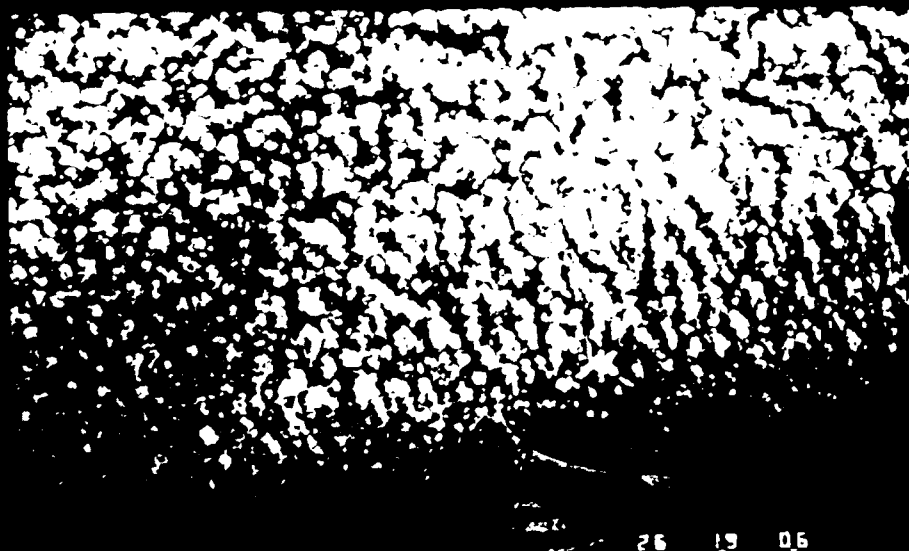
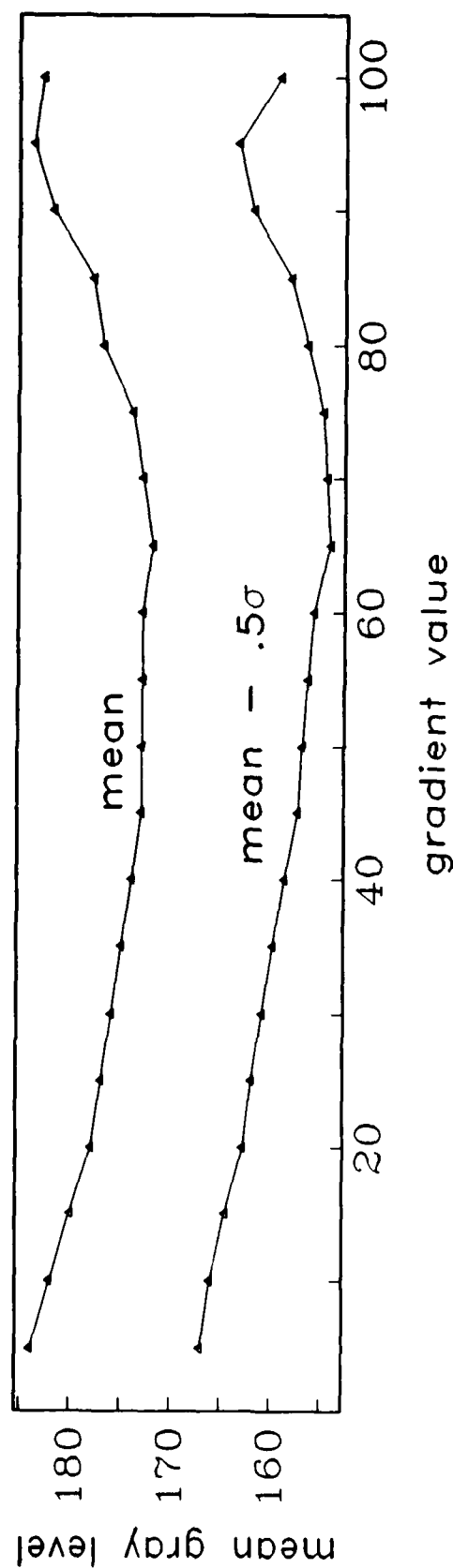


Figure 15 Example of the gradient and thresholded image

Cape Canaveral No.2

Mean gray value vs gradient distribution



Cumulative percentage of total gradient

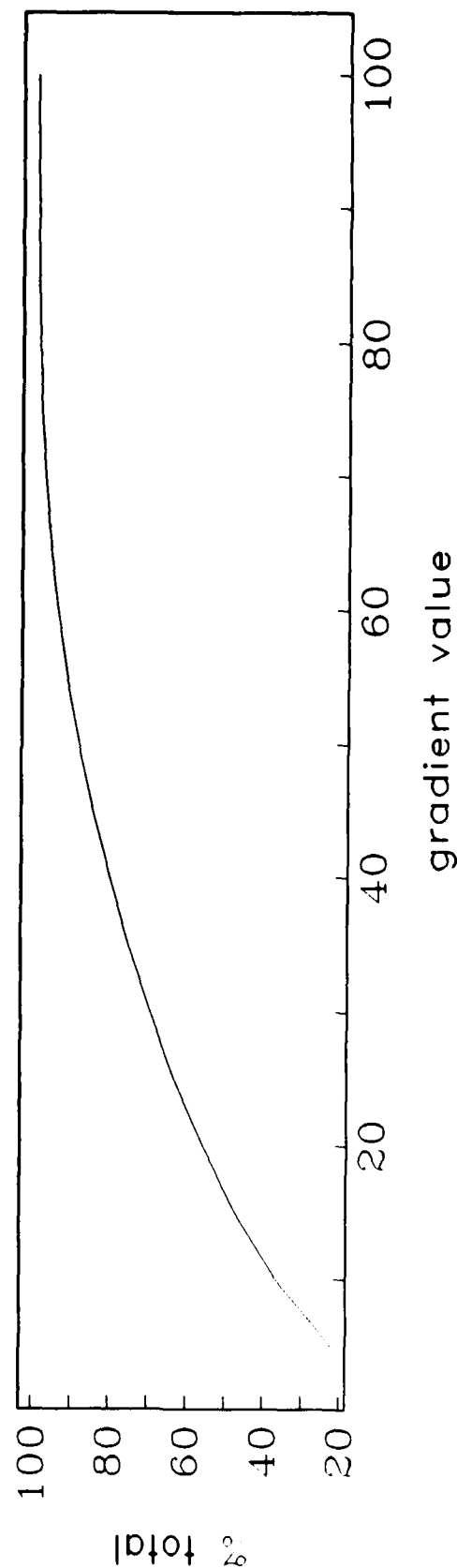


Figure 16 Plots for gradient method approach

Variance vs Mean gray level CC N0.2 window size 5

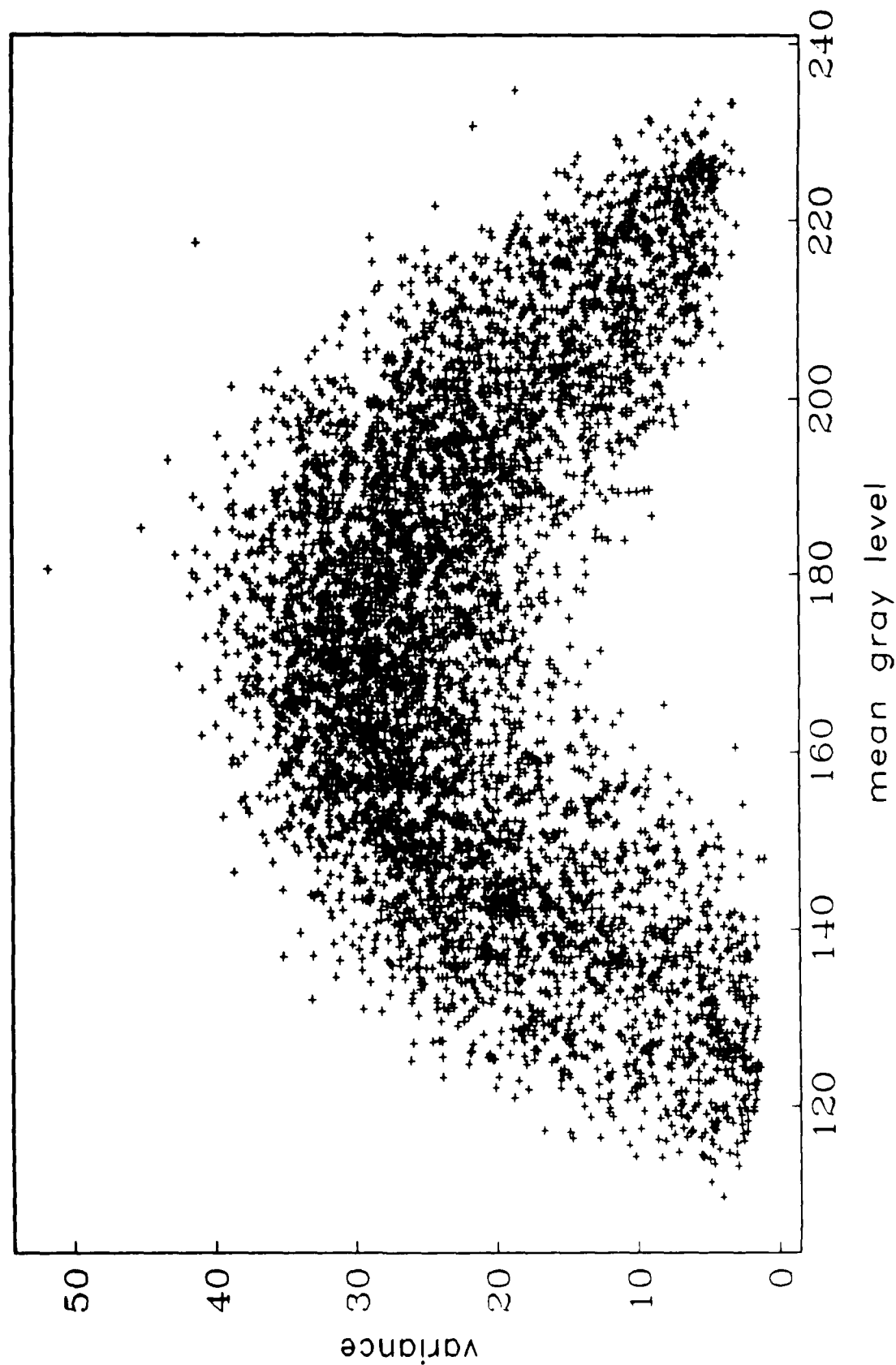


Figure 17 An arch for 5x5 box of horizontal homogeneity method

Variance vs Mean gray level CC N0.2 window size 7

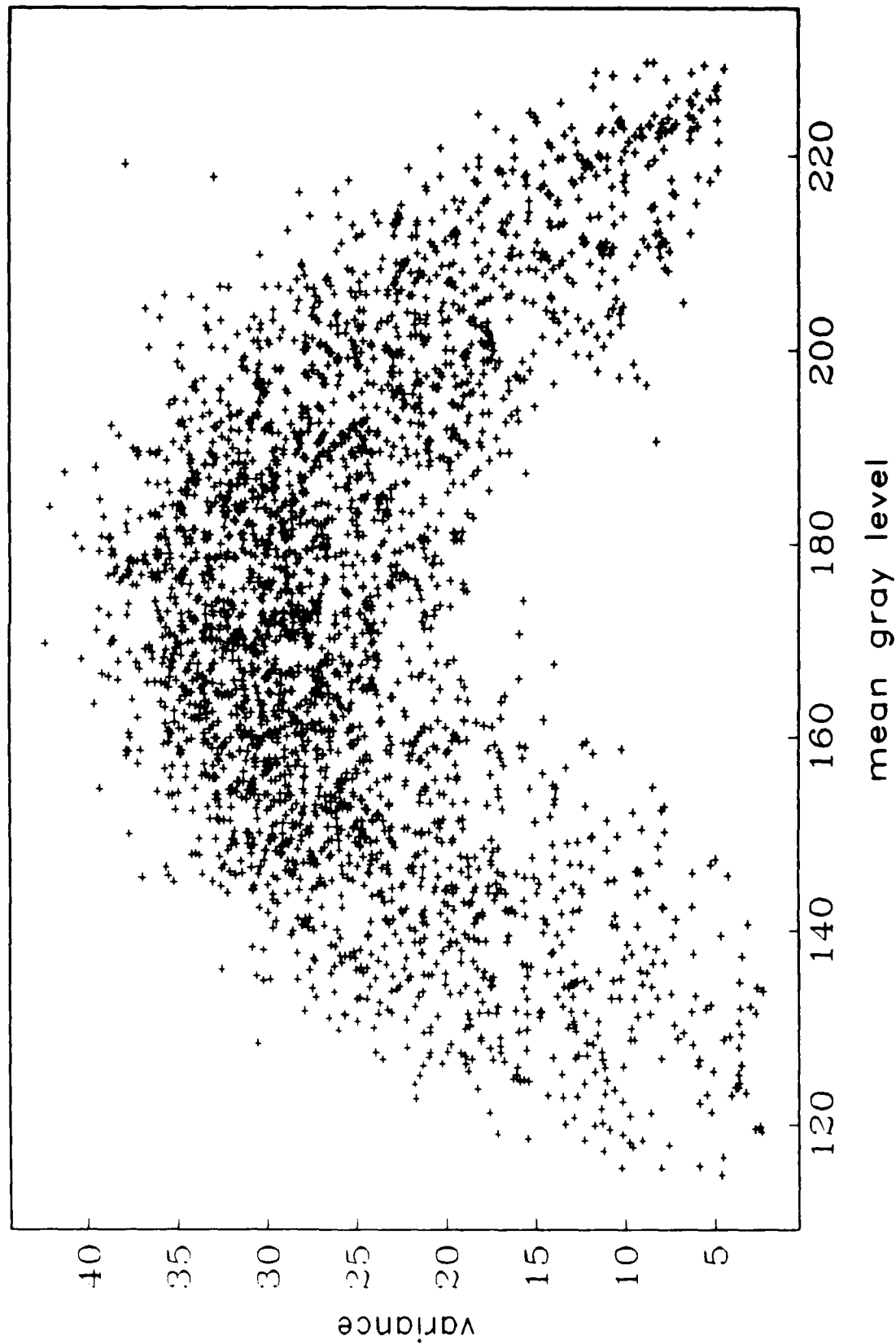


Figure 18 An arch for 7x7 box of horizontal homogeneity method

Cape Canaveral No.2 window size = 5

Histogram of Variance ≤ 5 Mean < 180

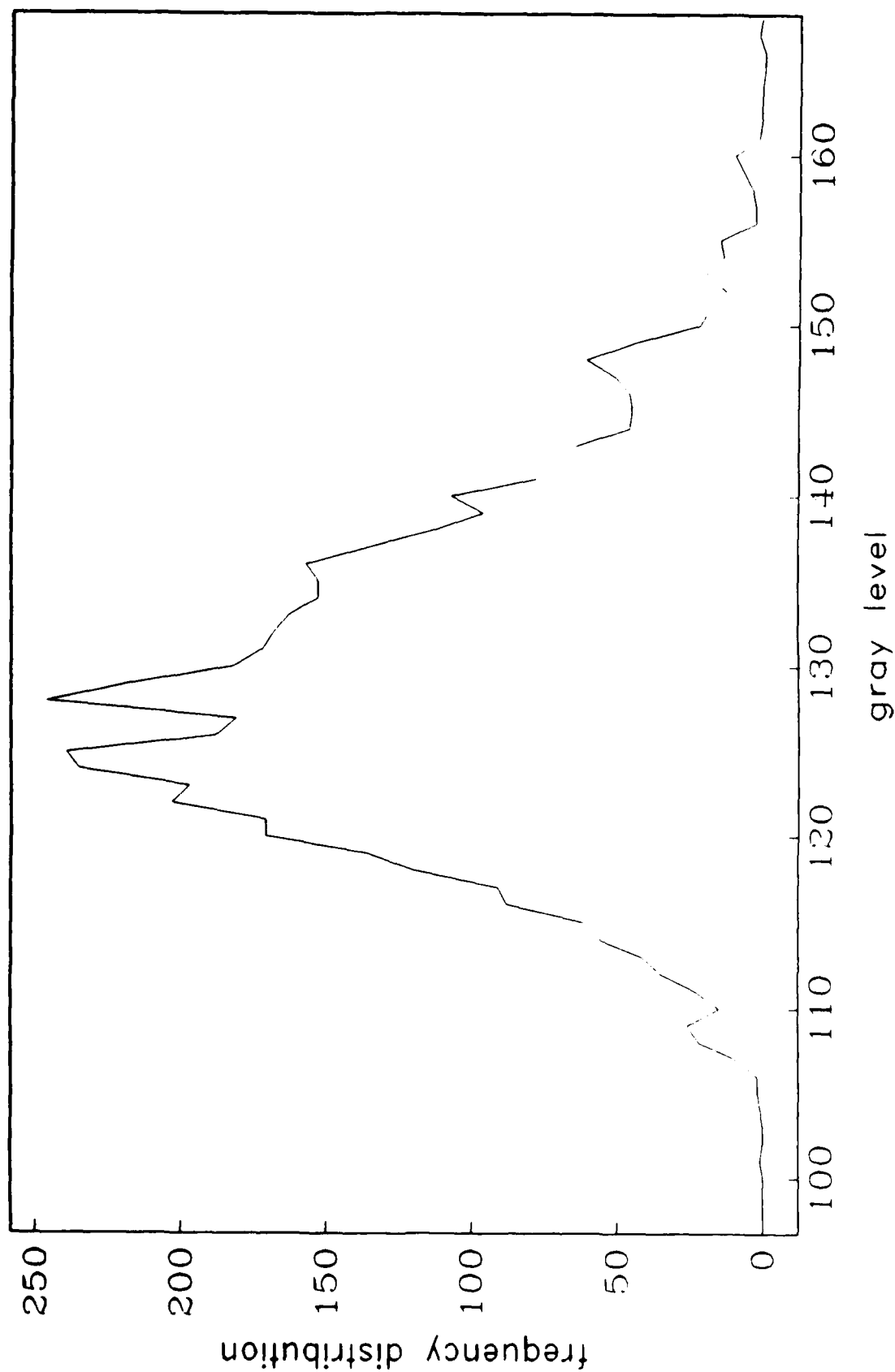


Figure 19 Histogram for the left foot of an arch for box size 5, 5

Cape Canaveral No.2 window size = 7

Histogram of Variance ≤ 5 Mean < 180

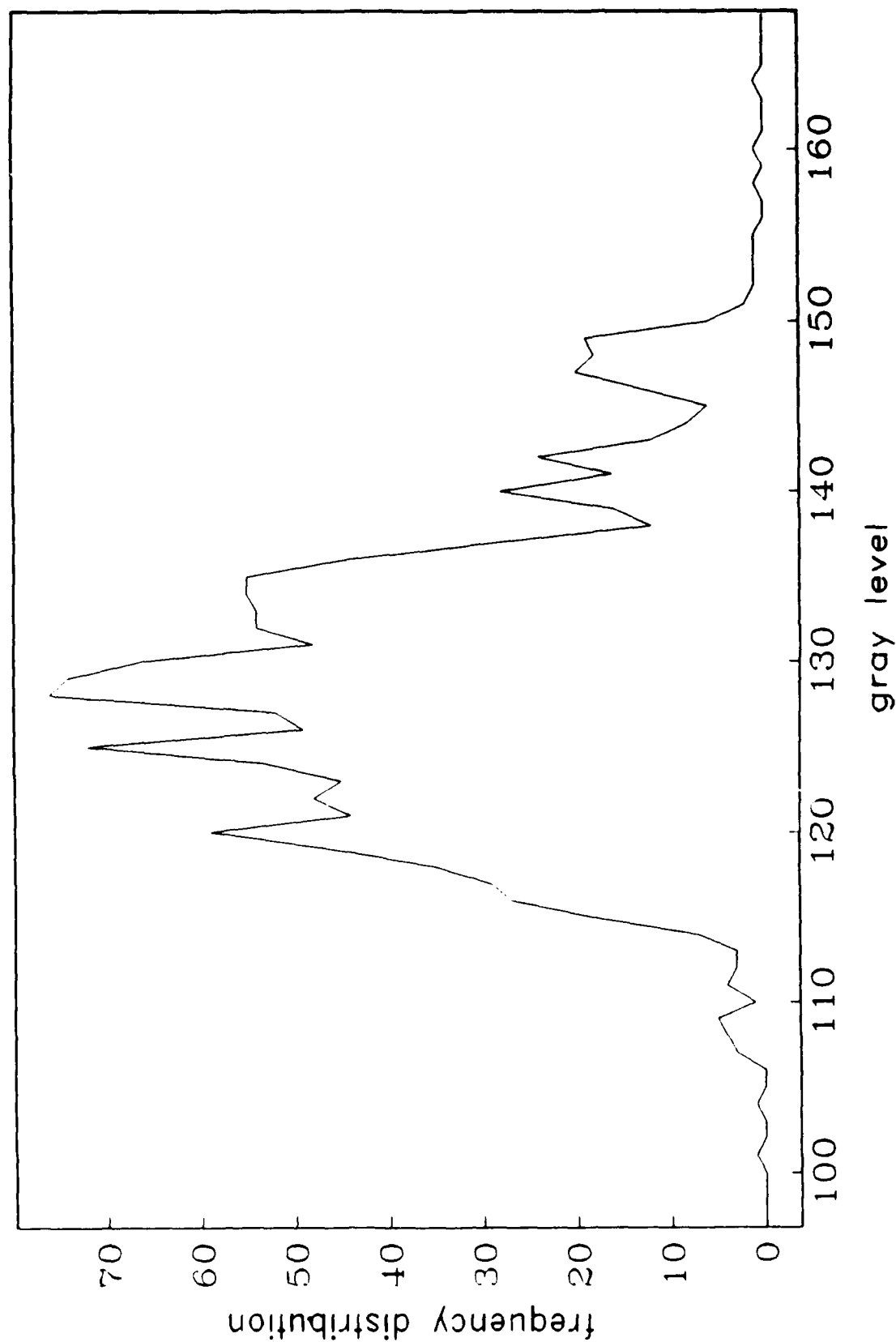
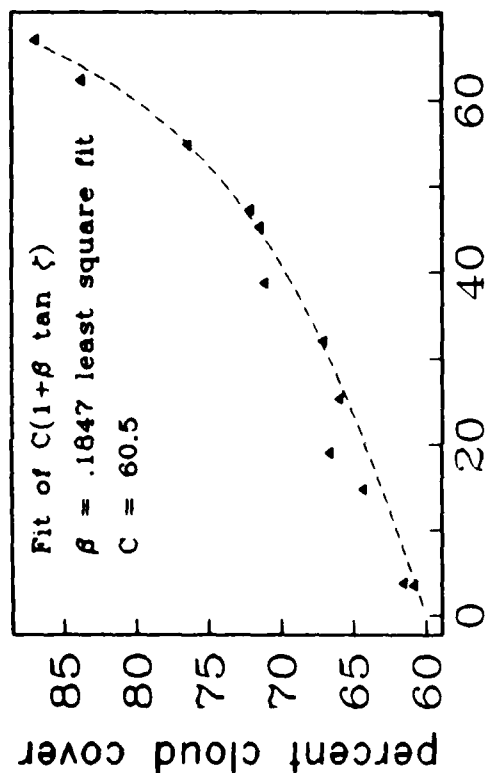


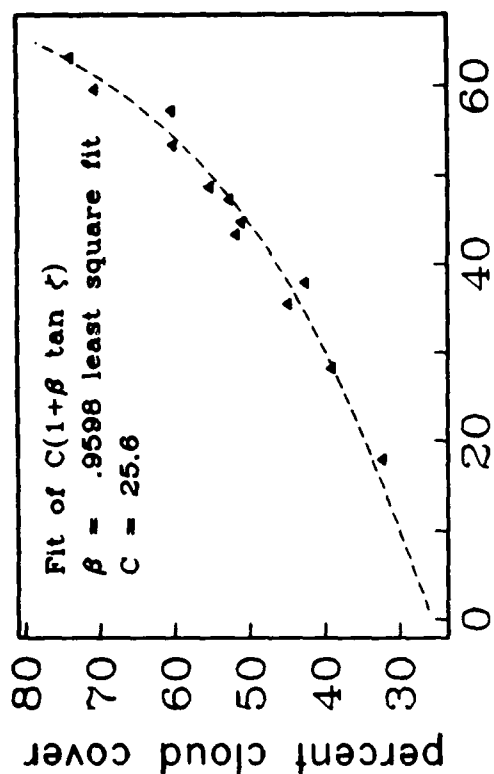
Figure 20 Histogram for the left foot of an arch for box size 7x7

Cloud Cover vs. Viewing Angle

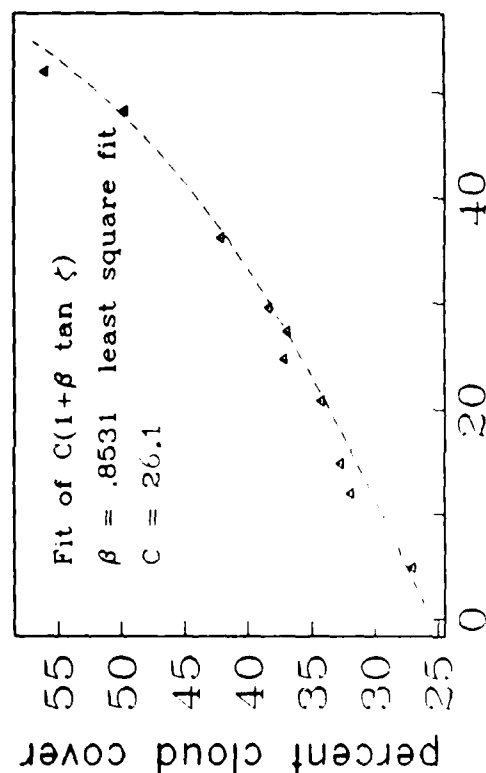
Cape Canaveral



Maui Island

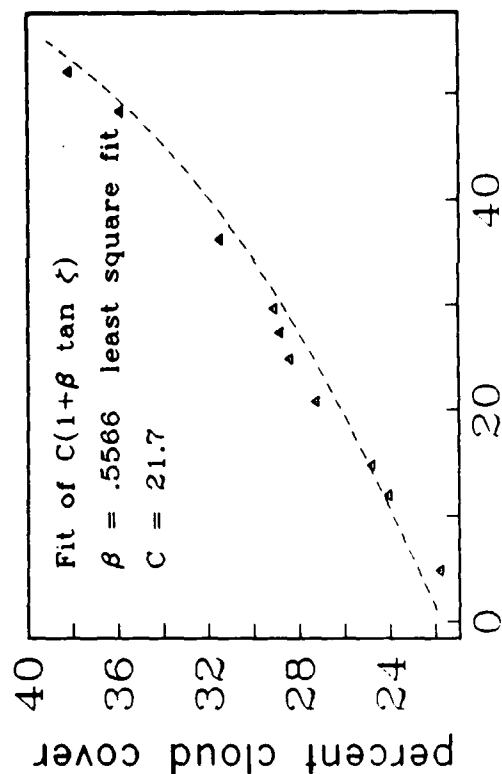


Gran Canary Island
clouds over land



viewing angle in degrees

Gran Canary Island
clouds over water



viewing angle in degrees

Figure 21 Final results for all four digitized sequences

APPENDIX A

Maui sequence

The complete analysis described in the report was also performed on a sequence of images taken during space shuttle mission 51C close to Maui Island, Hawaii. Twenty images were taken and navigation analysis produced a following table

Flight 51C Shuttle "Discovery"

280 km orbit

image #	camera		target		camera up vector			angle in degrees
	lat (N)	long (W)	lat (N)	long (W)	X	Y	Z	
1	21.60	156.52	20.820	156.520	0.0	-0.16	-1.0	17.96
2	21.97	155.98	20.758	156.435	0.0	-0.18	-1.0	28.16
3	22.17	155.64	20.700	156.560	0.0	-0.16	-1.0	35.47
4	22.30	155.40	20.750	156.480	0.0	-0.16	-1.0	37.82
5	22.46	155.01	20.740	156.550	0.0	0.00	-1.0	43.37
6	22.53	154.81	20.725	156.425	0.0	0.00	-1.0	44.80
7	22.62	154.59	20.740	156.455	0.0	0.14	-1.0	47.34
8	22.66	154.45	20.712	156.425	0.0	0.08	-1.0	48.79
9	22.85	153.80	20.841	156.400	0.0	0.08	-1.0	53.46
10	22.97	153.28	20.870	156.400	0.0	0.23	-1.0	57.27
11	23.01	152.98	20.700	156.300	0.0	0.14	-1.0	59.61
12	23.09	152.38	20.760	156.460	0.0	0.31	-1.0	63.24

Figures 23-30 provide the supporting study of the sequence and result in the final analysis table below. Figure 22 shows the area chosen for the study.

Results of Cloudiness vs Viewing Angle Study

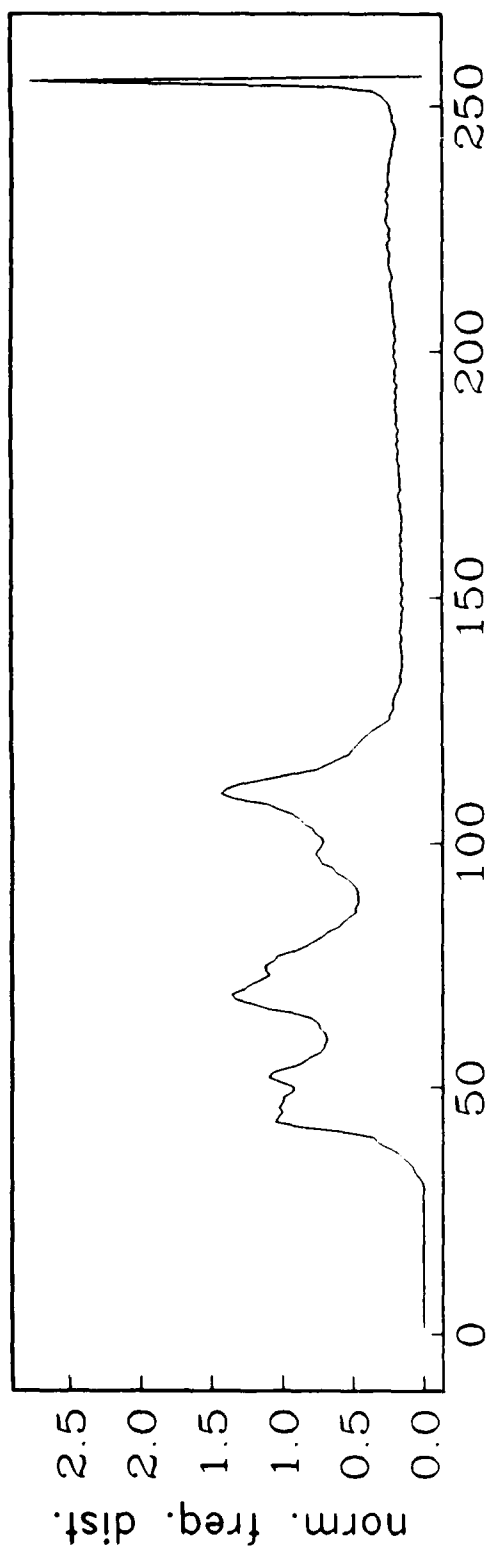
image #	gradient cutoff	mean gray level	sigma (σ)	mean-.5 σ gray level	percent cloudiness	angle in degrees
1	58=90.28%	159	46.0	136	32.26%	17.96
2	60=90.02	156	48.5	132	38.99	28.16
3	59=89.91	163	48.4	139	44.84	35.47
4	45=89.90	135	39.7	115	42.55	37.82
5	61=90.00	174	48.9	150	51.80	43.37
6	51=90.03	168	44.7	146	51.02	44.80
7	47=90.13	184	43.6	162	52.63	47.34
8	45=90.26	181	41.8	160	55.28	48.79
9	51=90.12	188	43.4	166	60.19	53.46
10	54=90.12	186	43.0	164	60.36	57.27
11	40=90.17	203	35.5	185	70.50	59.61
12	66=89.97	180	47.3	156	73.75	63.24

The plots for the navigation track of the shuttle and final study of cloudiness vs viewing angle are given in Figures 9 and 21 respectively.



Figure 22 Region inside triangle was taken for analysis

Histogram of Original Maui No.1



Histogram of Equalized Maui No.1

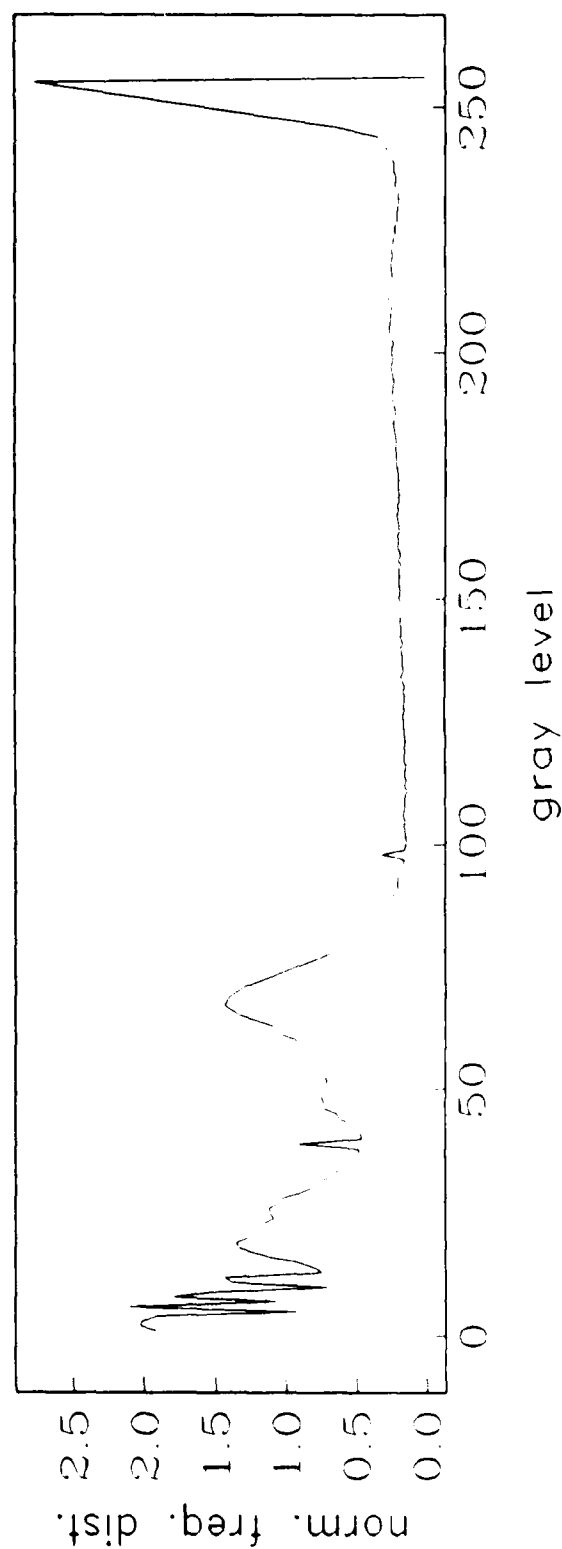


Figure 2. Histogram of the image before and after equalization

Gray Value Distribution - row 226 - Maui No.1

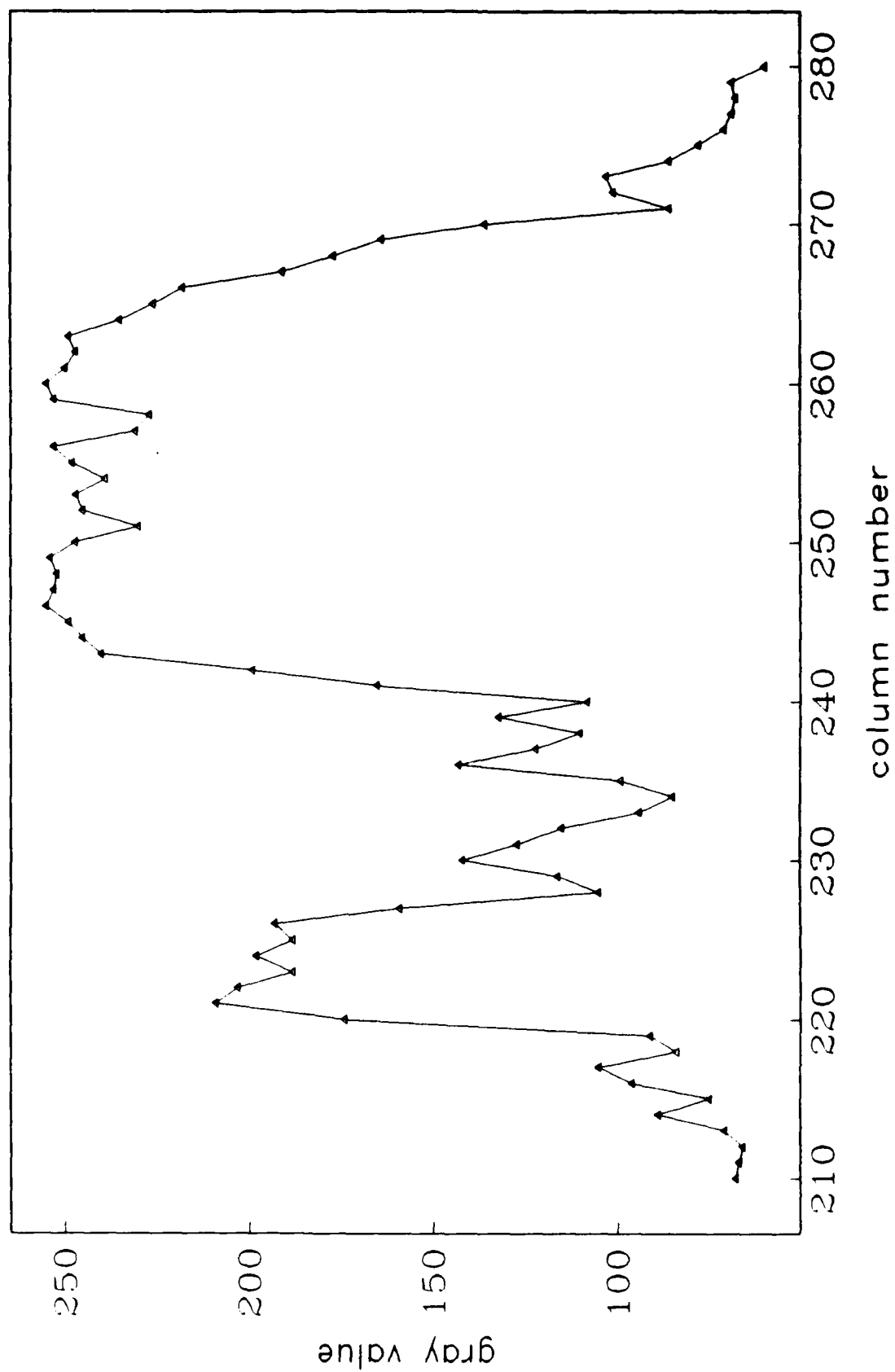


Figure 24 Example of gray value distribution in a sample image row

Maui No.1

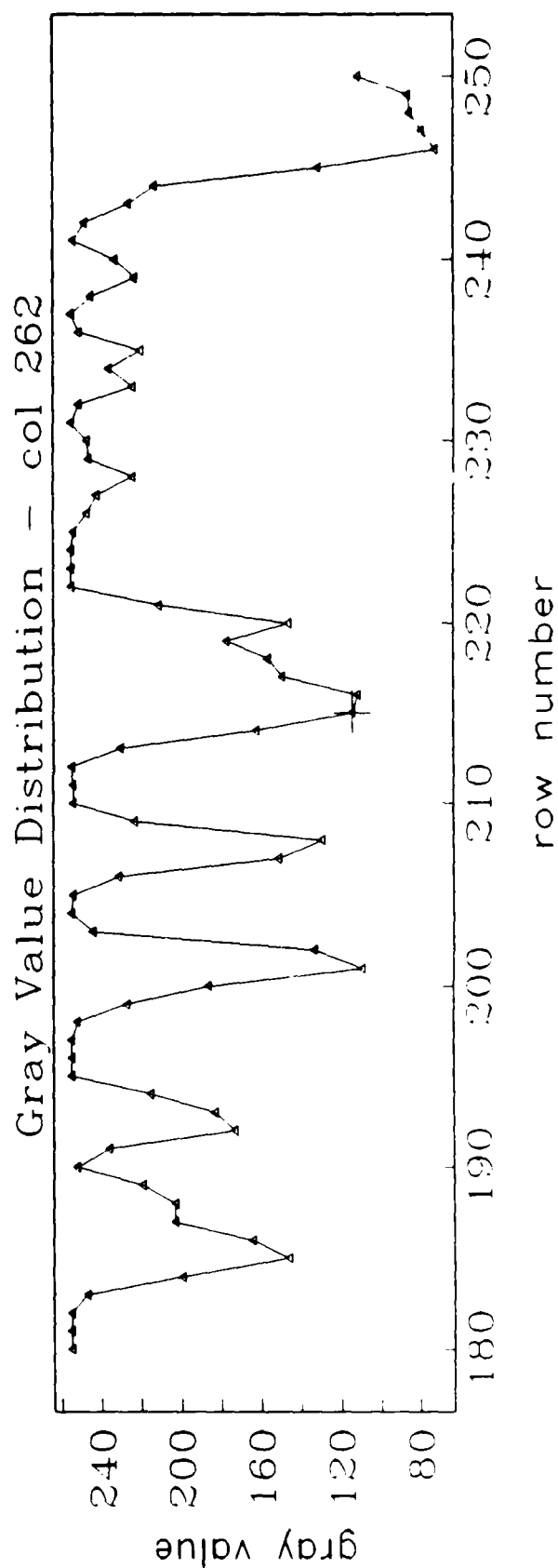
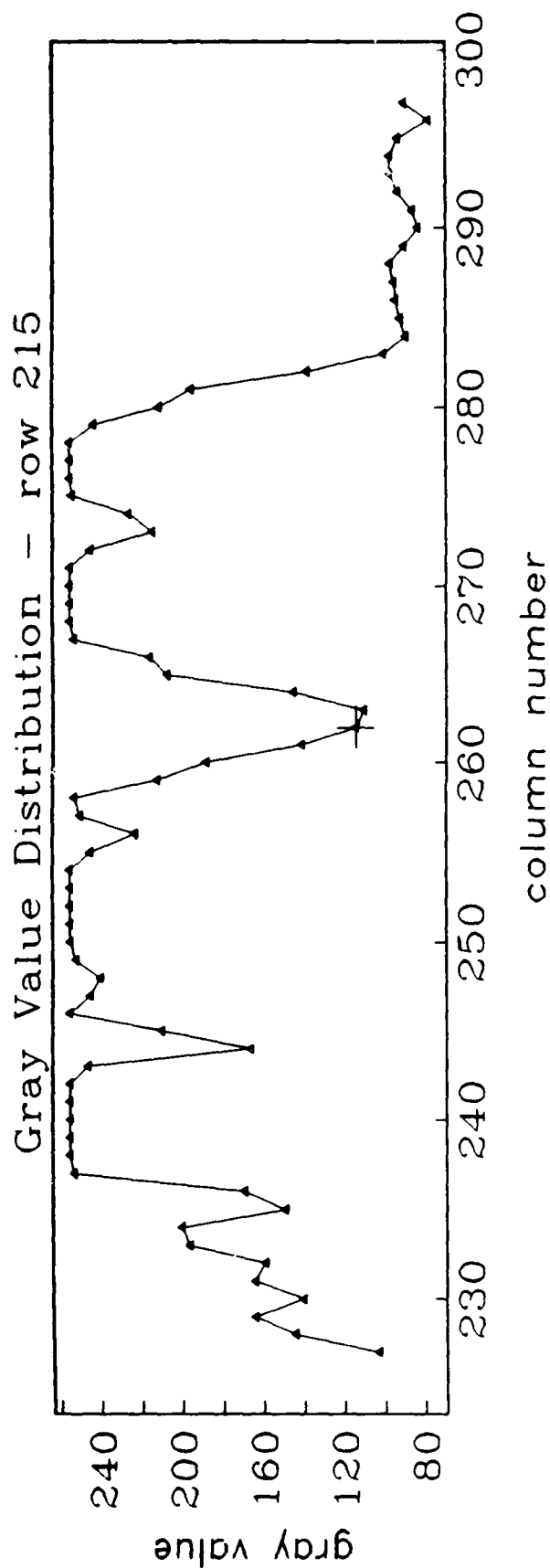
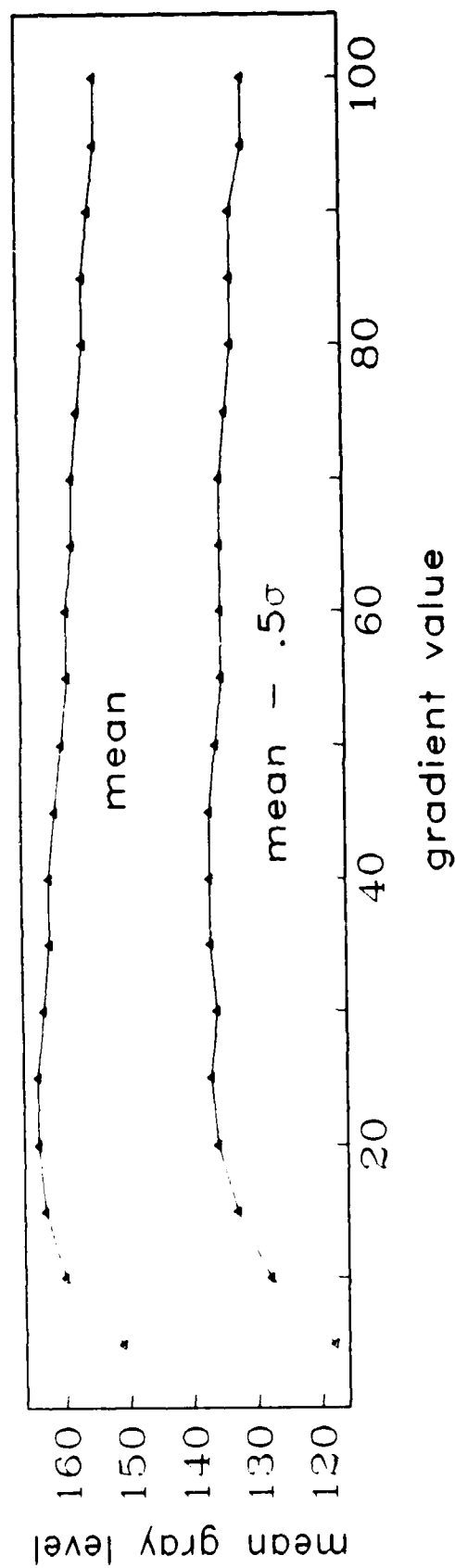


Figure 25 Example of gray value distribution in a row-column test

Maui No.1

Mean gray value vs gradient distribution



Cumulative percentage of total gradient

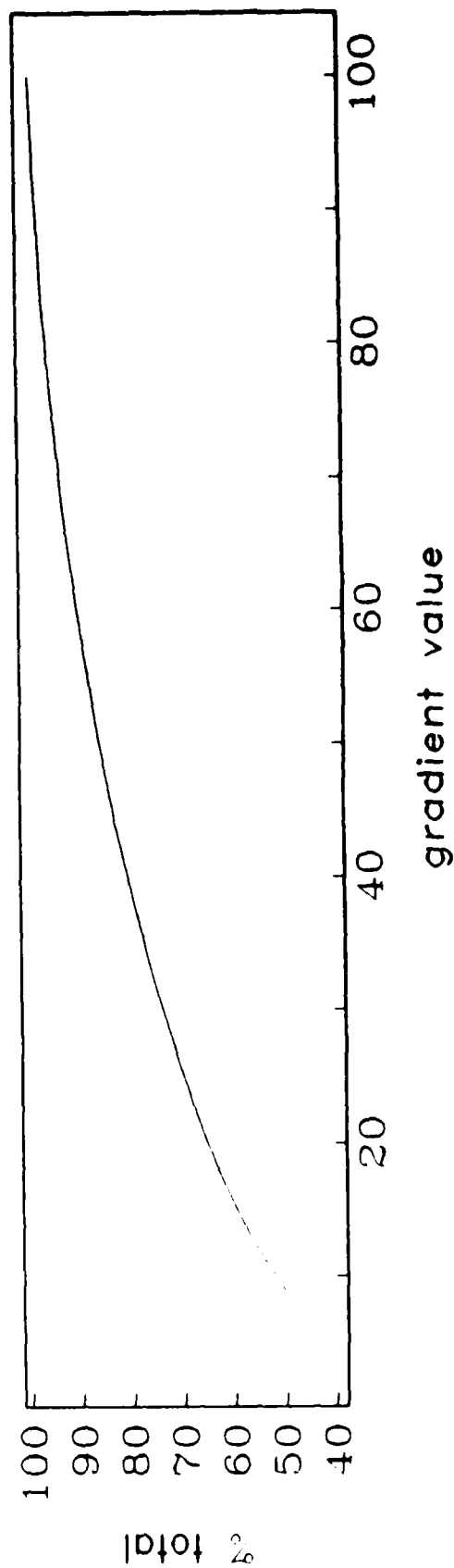


Figure 26 Plots for gradient method approach

Variance vs Mean gray level Maui N0.1 window size 5

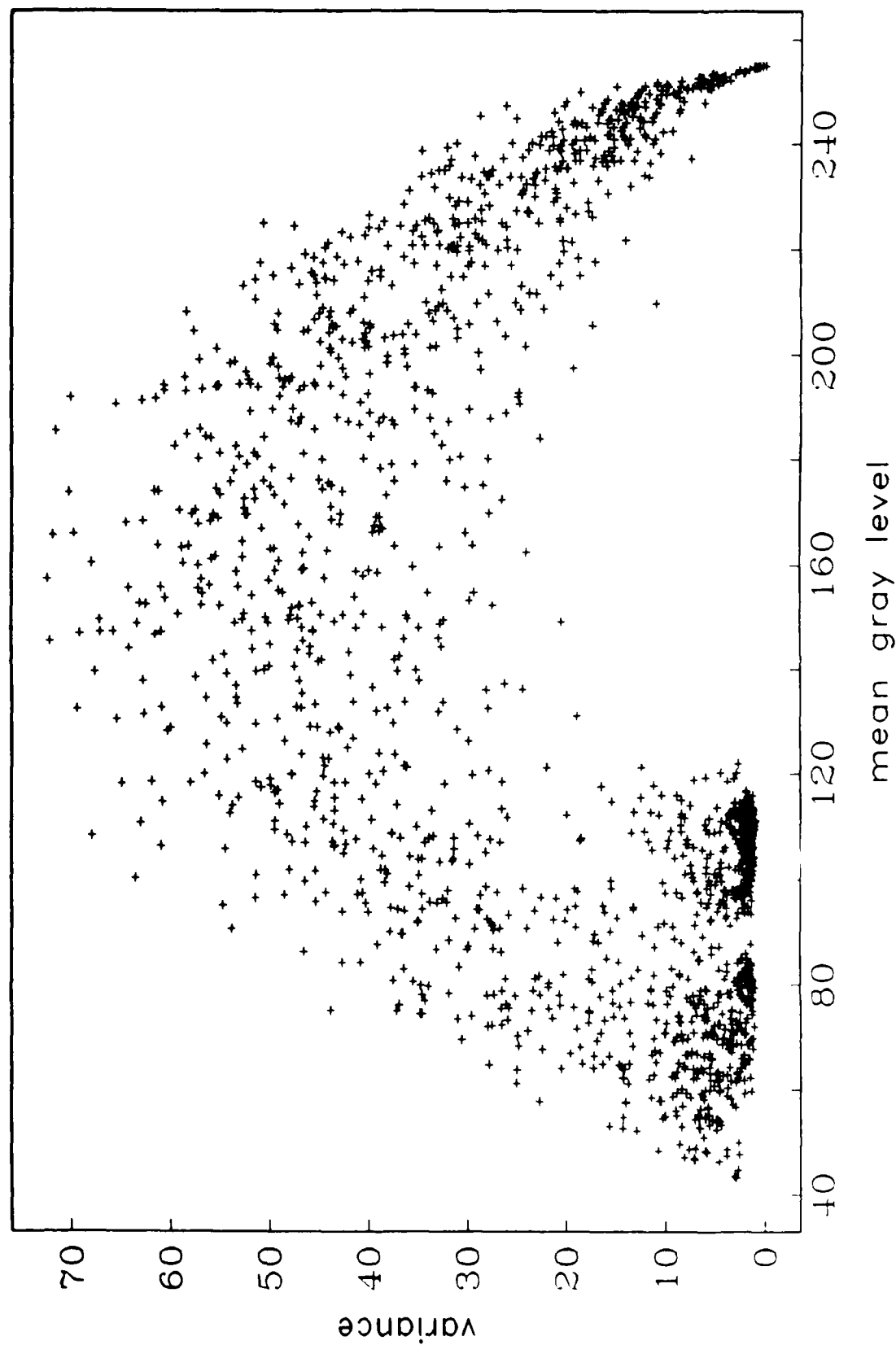


Figure 2: An arch for 5x5 box of horizontal homogeneity method

Variance vs Mean gray level Maui N0.1 window size 7

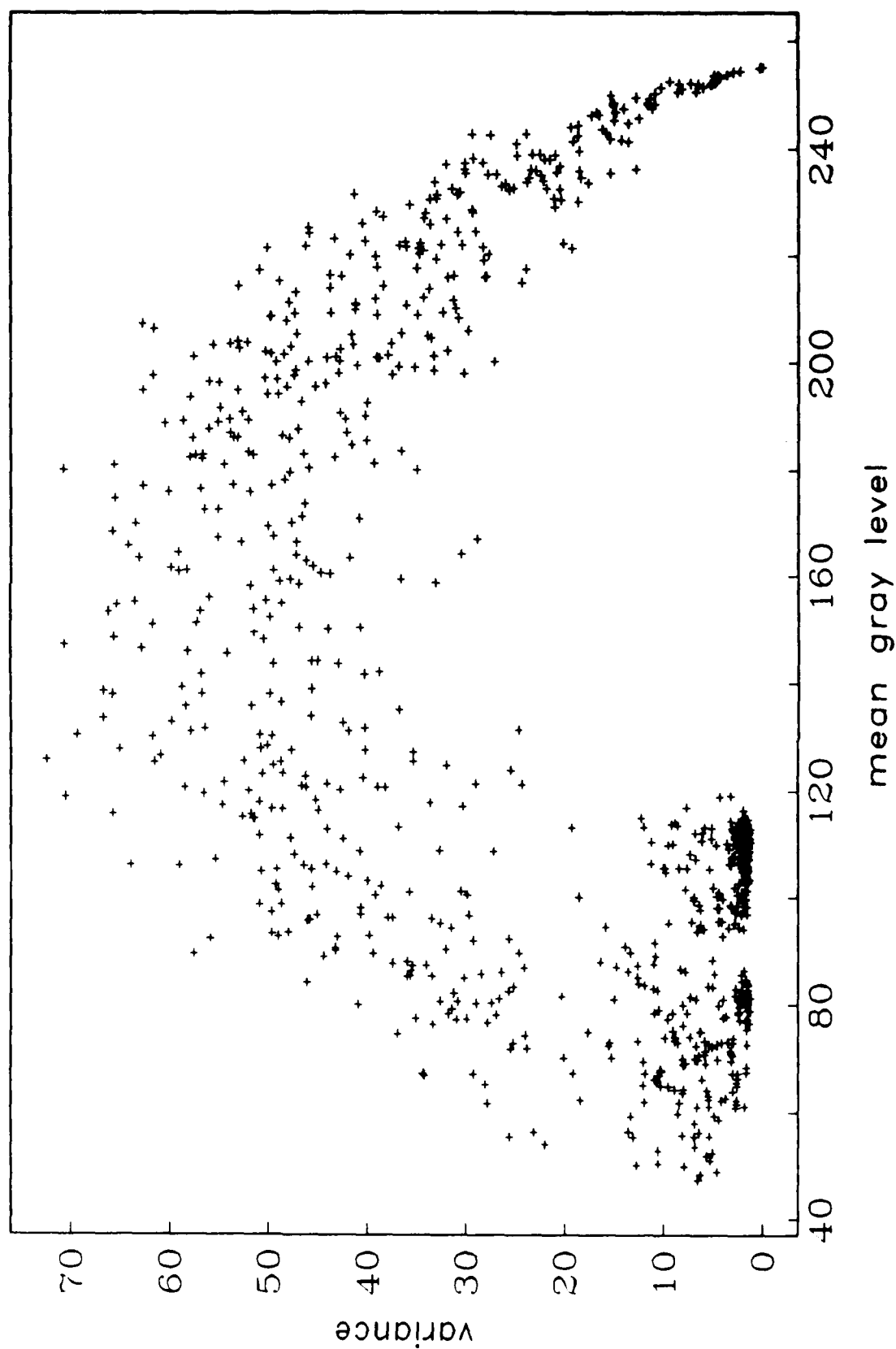


Figure 28 An arch for 7x7 box of horizontal homogeneity method

Maui No.1 window size = 5
Histogram of Variance ≤ 5 Mean < 180

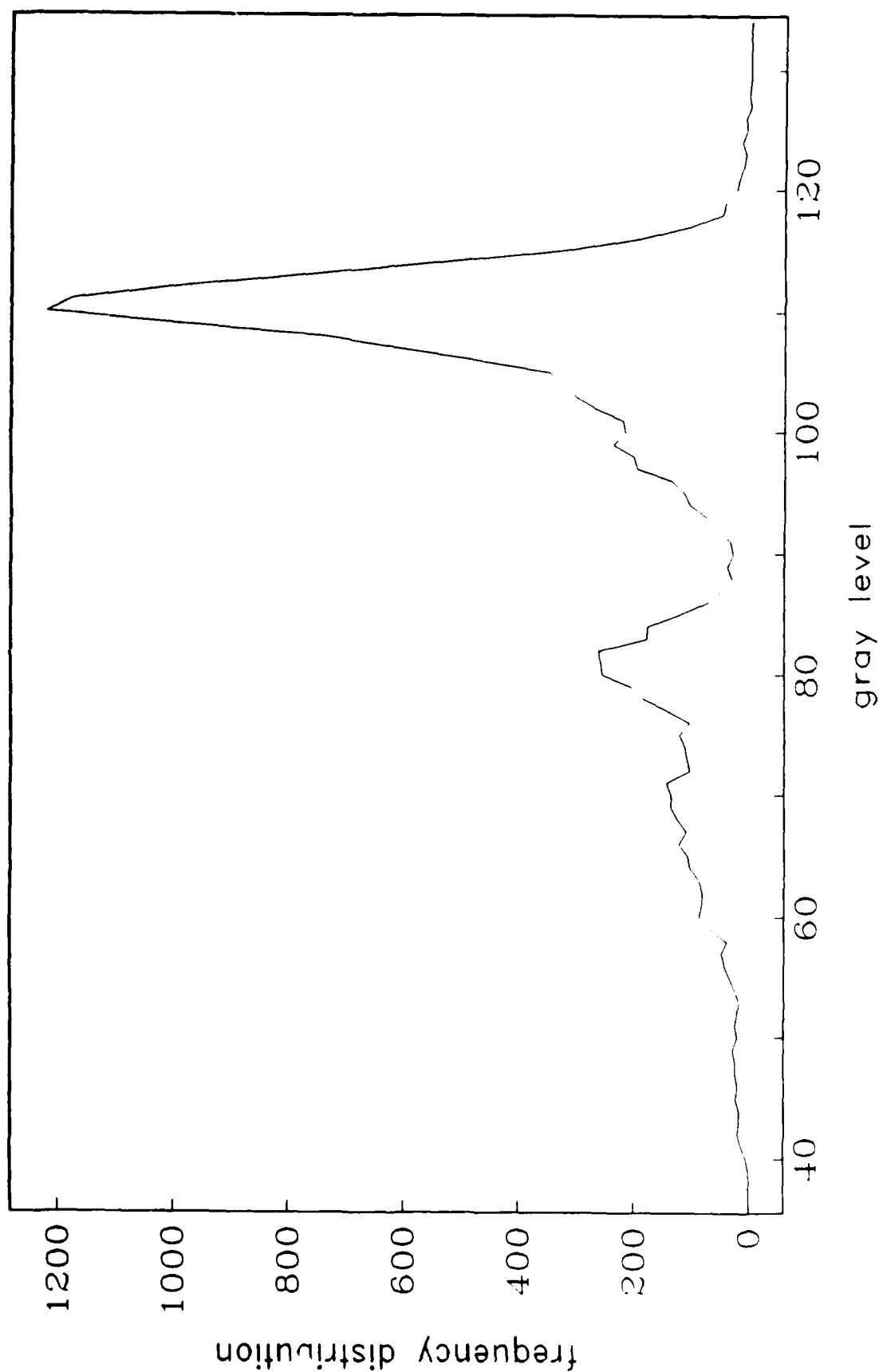


Figure 2' Histogram for the left foot af an arch for box size 5x5

Maui No.1 window size = 7
Histogram of Variance ≤ 5 Mean < 180

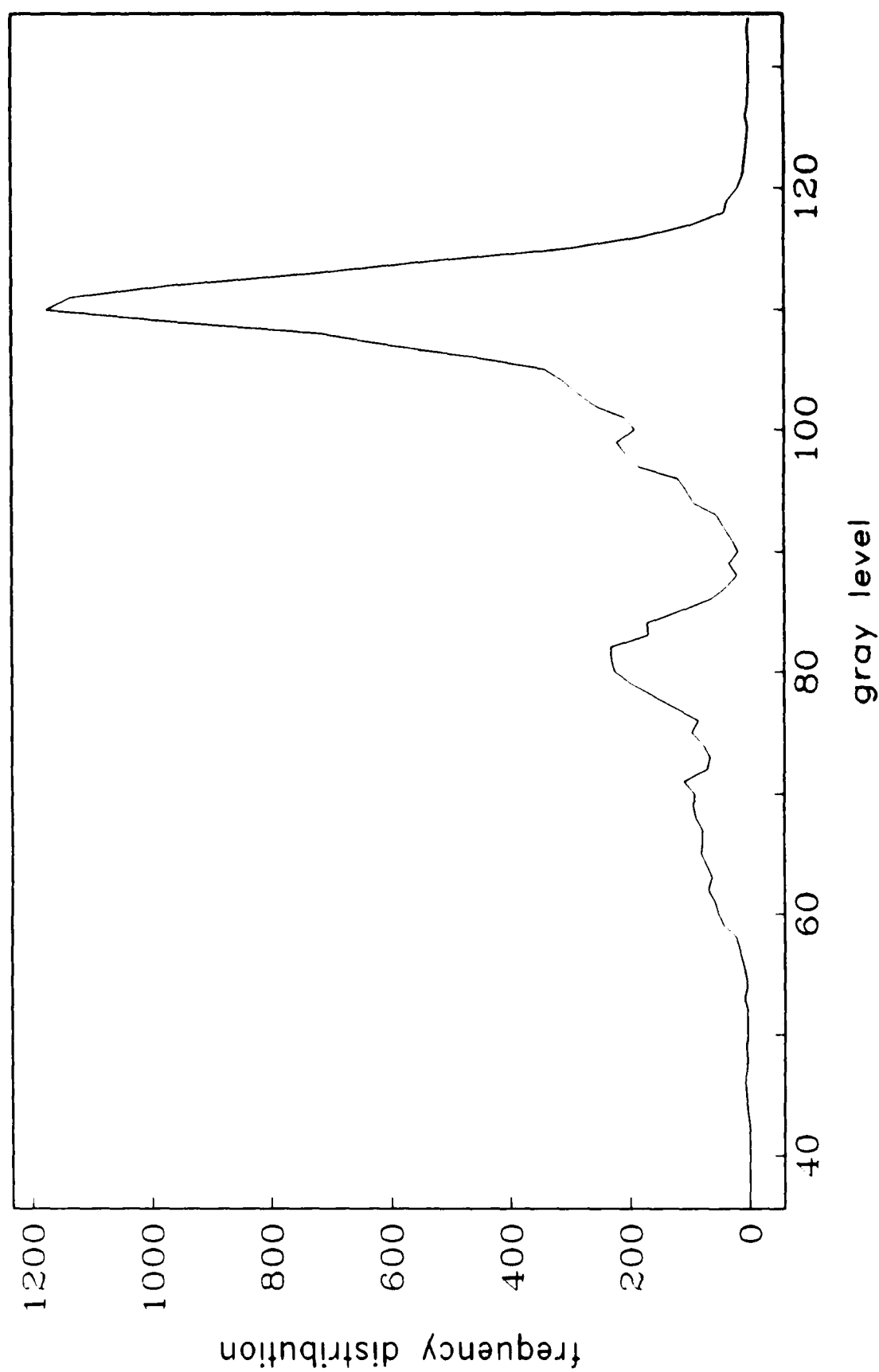


Figure 30 Histogram for the left foot of an arch for box size 7x7

APPENDIX B

Gran Canary sequence

The complete analysis described in the report was also performed on a sequence of images taken during space shuttle mission 51C over Gran Canary Island. Twenty images were taken and navigation analysis produced a following table

Flight 51D Shuttle "Discovery"

265 km orbit

image #	camera		target		camera up vector			angle in degrees
	lat (N)	long (W)	lat (N)	long (W)	X	Y	Z	
6	27.63	16.700	27.850	15.560	0.0	-0.7	0.05	24.40
5	27.63	16.500	27.840	15.560	0.0	-0.7	0.05	20.63
4	27.62	16.200	27.860	15.575	0.0	-0.7	0.05	14.80
3	27.64	15.597	27.835	15.597	0.0	-0.7	0.10	4.88
1	27.62	14.950	27.790	15.460	0.0	-0.7	0.17	11.93
7	27.63	14.200	27.880	15.500	0.0	-0.7	0.05	27.37
8	27.63	14.100	27.858	15.535	0.0	-0.7	0.11	29.59
9	27.64	13.750	27.875	15.600	0.0	-0.7	0.13	36.17
11	27.63	12.700	27.850	15.520	0.0	-0.7	0.16	48.30
12	27.62	12.300	27.865	15.500	0.0	-0.7	0.16	52.06

Analysis of this sequence varied from the previous, two separate areas were taken from this sequence. One area was over clearly over water and another over land. The areas are indicated in Figures 31 and 32. Figures 33-47 provide the supporting study of the sequence and result in the final analysis tables below for two areas indicated.

Results of Cloudiness vs Viewing Angle Study

Gran Canary Island clouds over WATER

image #	gradient cutoff	mean gray level	sigma (σ)	mean-.5 σ gray level	percent cloudiness	angle in degrees
6	65=90.12%	183	40.1	163	28.82%	27.37
5	53=90.08	172	45.7	149	27.25	20.63
4	51=89.89	170	44.6	148	24.80	14.80
3	48=89.97	166	45.7	143	21.77	4.88
1	91=90.16	173	45.7	150	24.05	11.93
7	49=90.01	151	48.8	127	28.43	24.80
8	52=90.00	152	44.7	130	29.10	29.59
9	53=90.21	170	44.5	148	31.50	36.17
11	54=90.04	173	41.4	152	35.90	48.30
12	54=90.18	188	38.4	169	38.15	52.06

Results of Cloudiness vs Viewing Angle Study

Gran Canary Island clouds over LAND

image #	gradient cutoff	mean gray level	sigma (σ)	mean-.5 σ gray level	percent cloudiness	angle in degrees
6	64=90.20%	179	46.3	156	36.91%	27.37
5	64=90.00	176	47.8	152	34.24	20.63
4	62=90.00	171	47.3	147	32.68	14.80
3	54=89.85	152	43.9	130	27.03	4.88
1	62=90.17	180	46.0	157	31.92	11.93
7	62=90.25	177	45.1	154	37.15	24.80
8	63=89.90	177	44.3	155	38.35	29.59
9	65=90.19	178	45.2	155	42.12	36.17
11	67=89.90	185	42.3	164	49.71	48.30
12	63=90.09	192	40.0	172	55.98	52.06

The plots for the navigation track of the shuttle and final study of cloudiness vs viewing angle are given in Figures 9 and 21 respectively.

The results produced apply to regions over water and over land.

3

Gran Canary over water



Figure 3: Region inside the box is taken for analysis over water

Gran Canary 3 over land

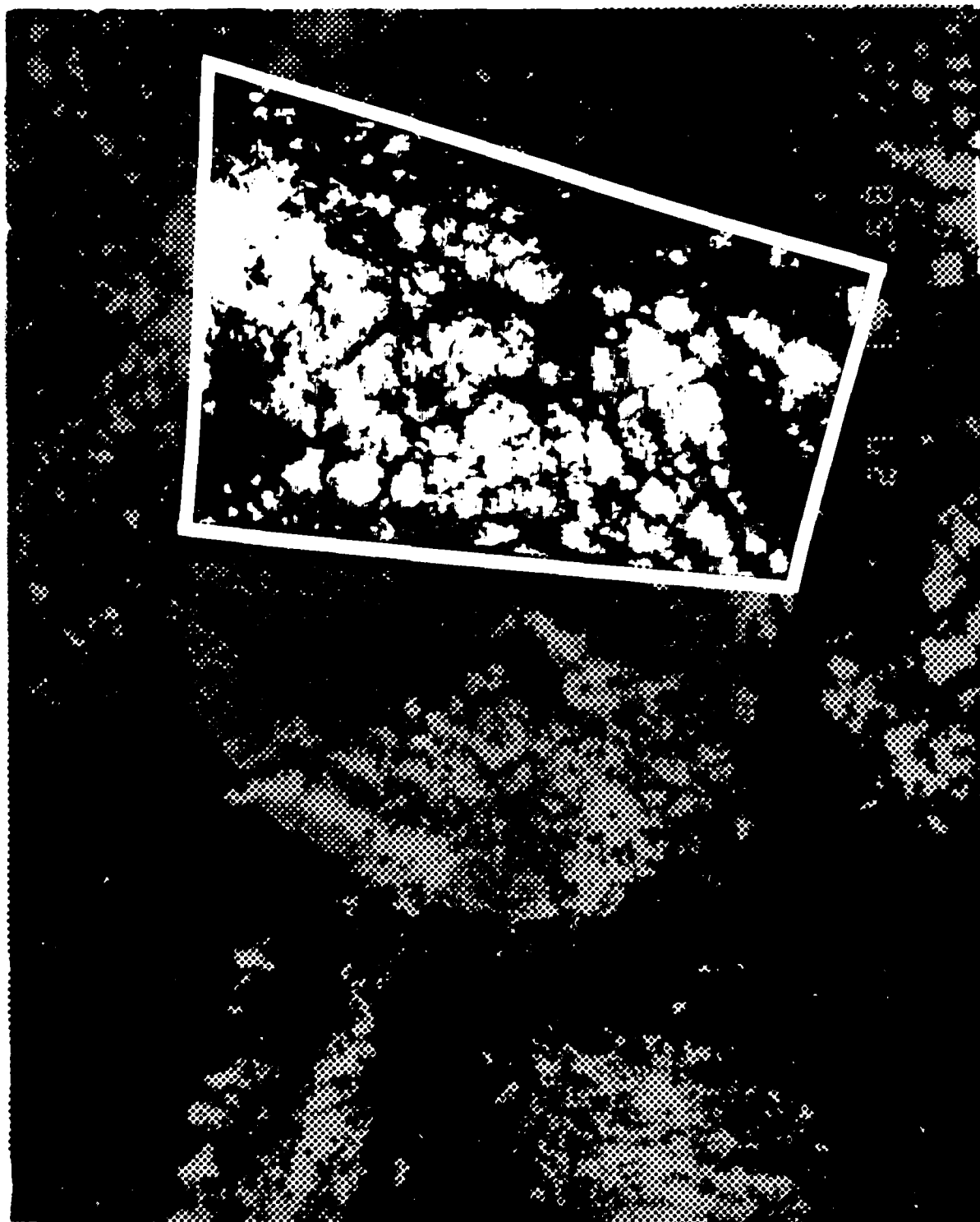
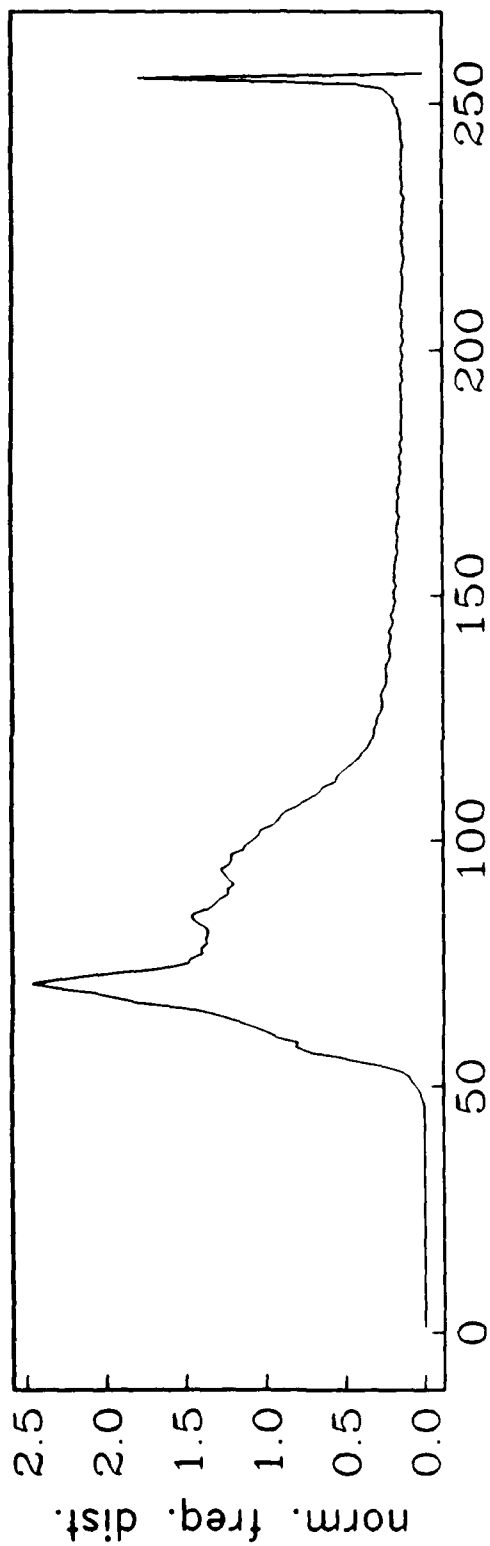


Figure 3.1 Region inside the box is taken for analysis over land

Histogram of Original Gran Canary No.1



Histogram of Equalized Gran Canary No.1

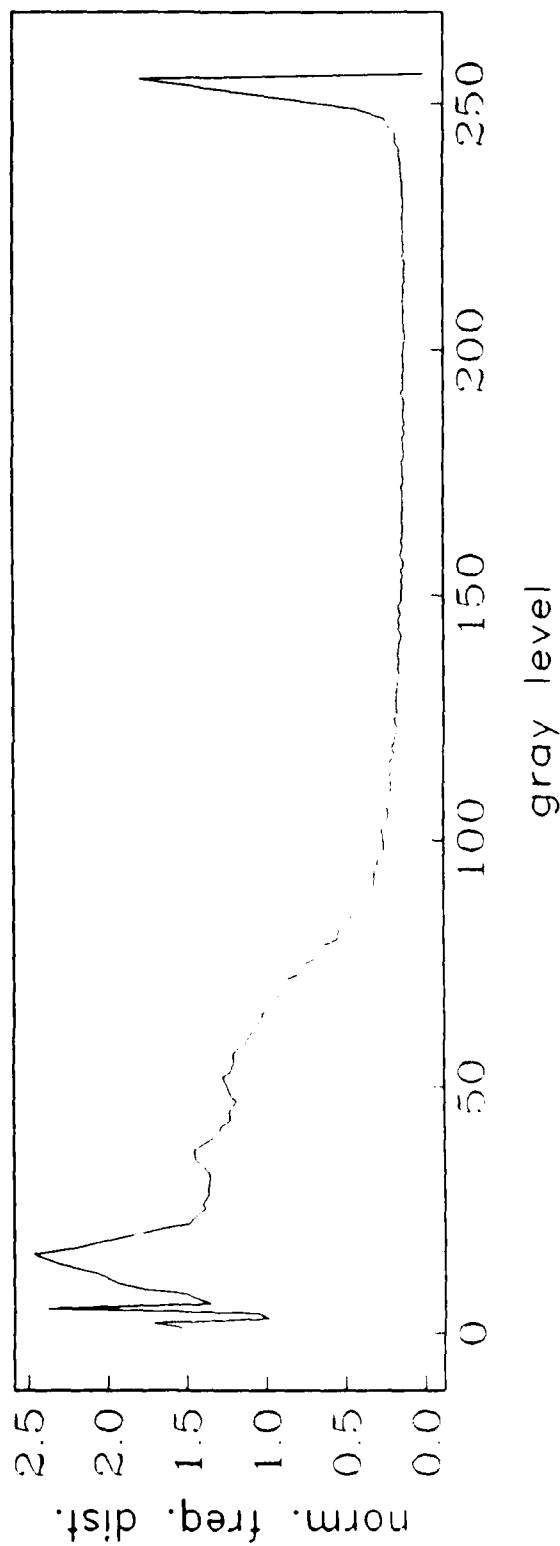


Figure 33 Histogram of the image before and after equalization

Gray Value Distribution - row 240 - Gran Canary No.3

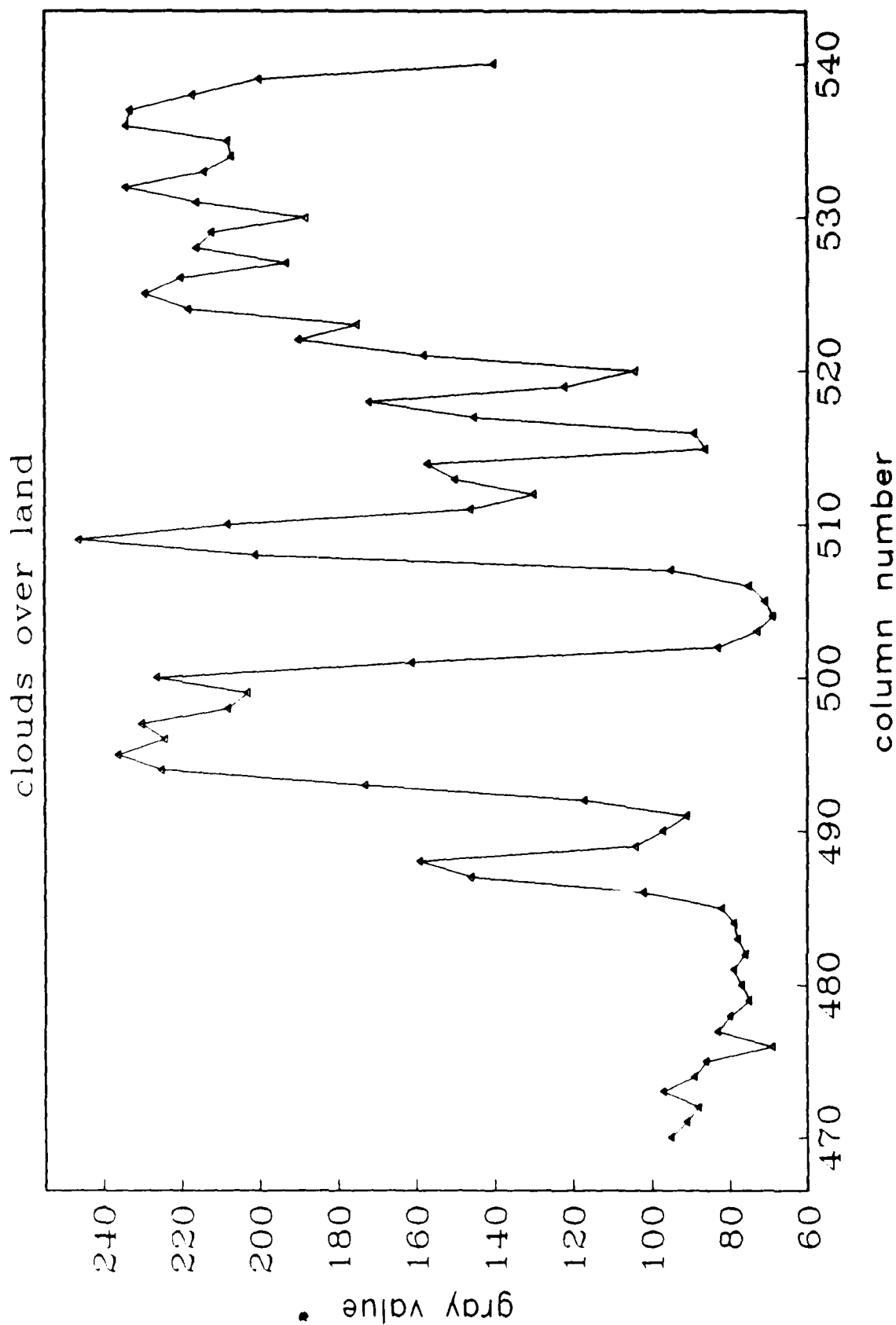


Figure 34 Example of gray value distribution in a sample image row of clouds over land

Gray Value Distribution - row 320 - Gran Canary No.3 clouds over water

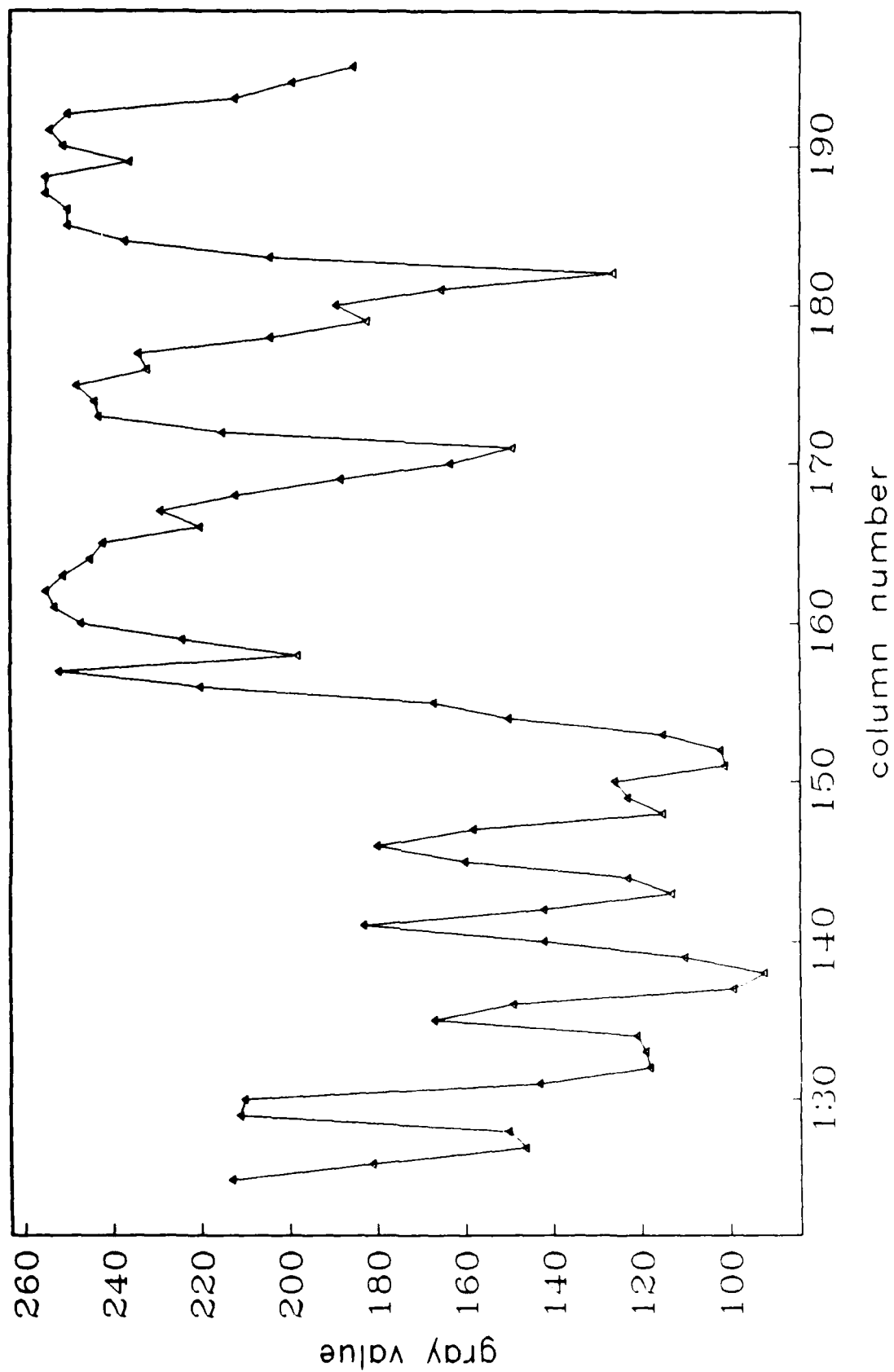


Figure 3 Example of gray value distribution in a sample image row of clouds over water

Gran Canary No.3 Clouds over water

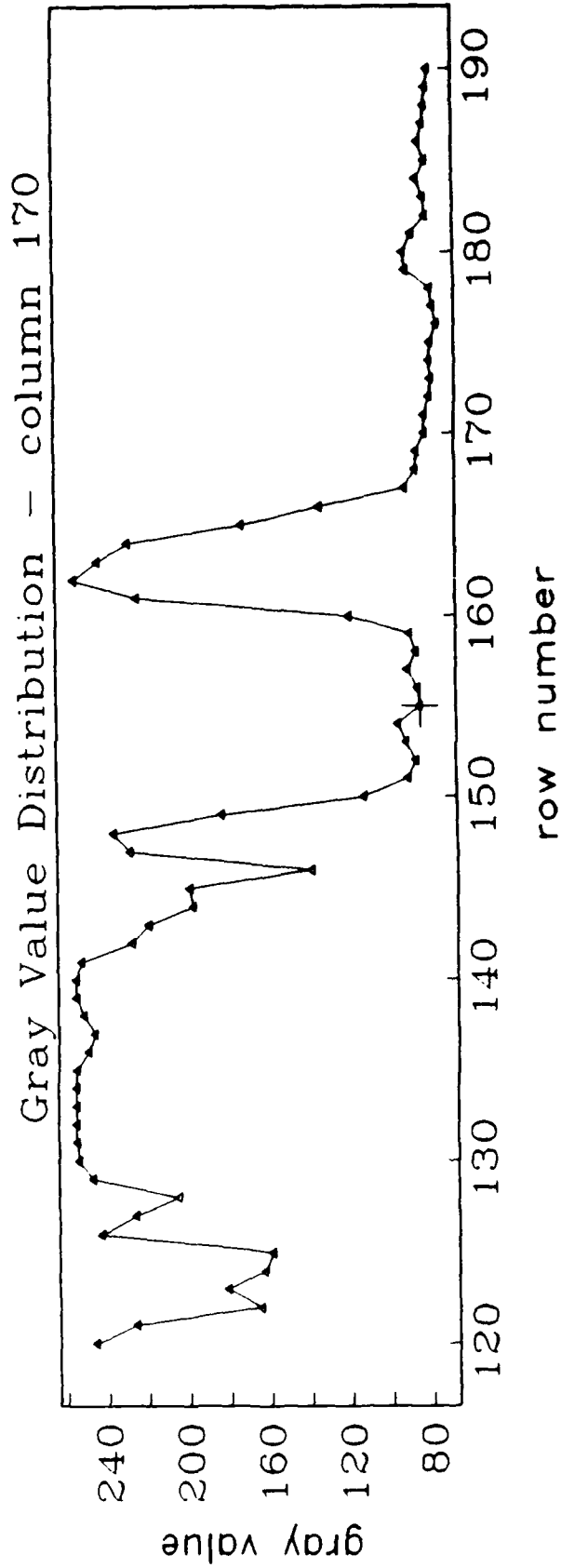
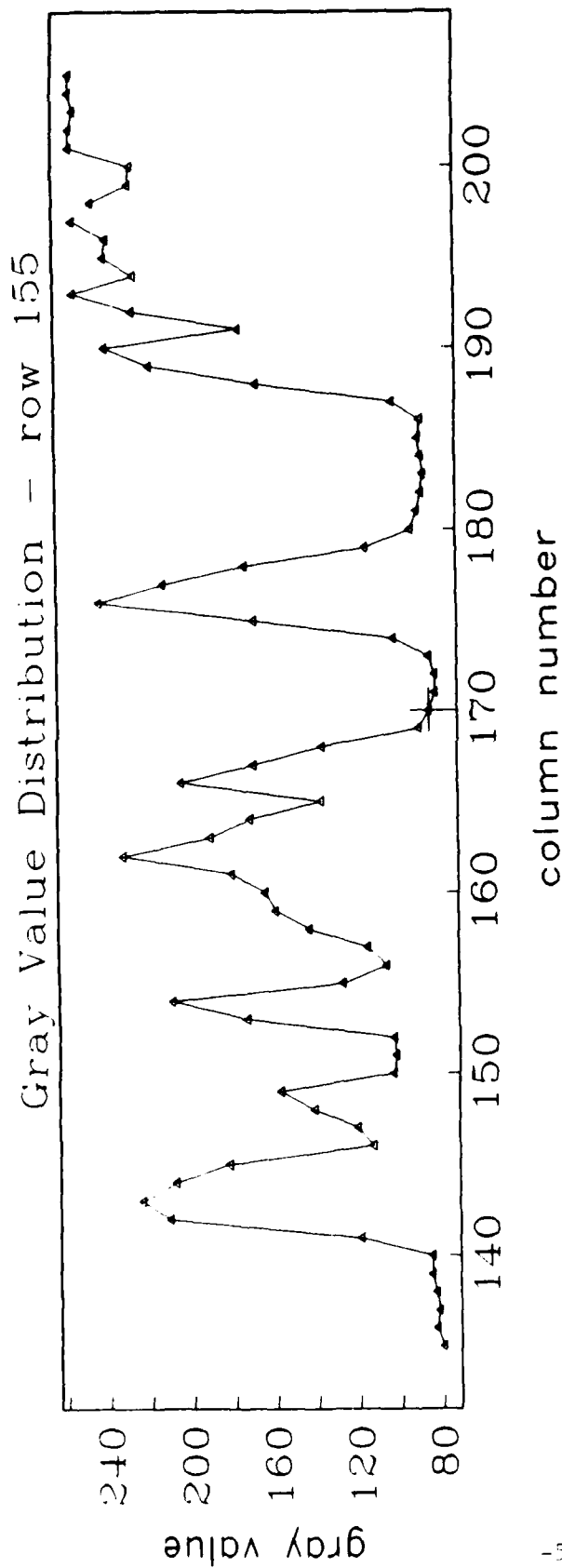
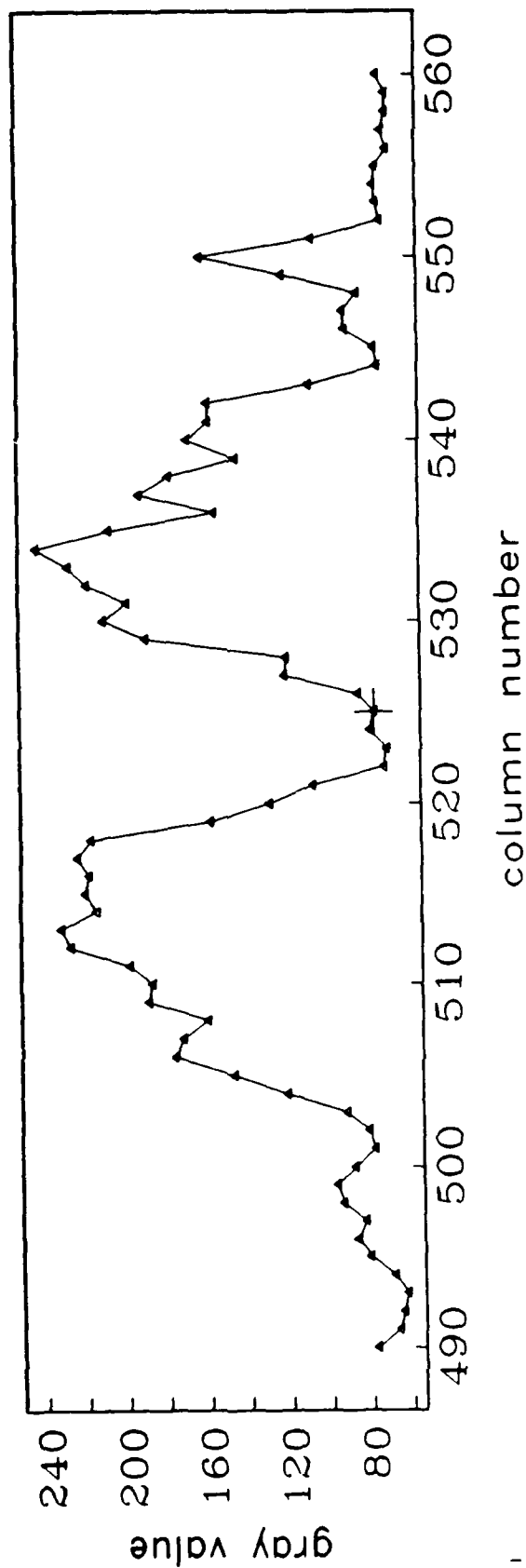


Figure 36 Example of gray value distribution in a row-column test over water

Gran Canary No.3 Clouds over land

Gray Value Distribution - row 263



Gray Value Distribution - col 525

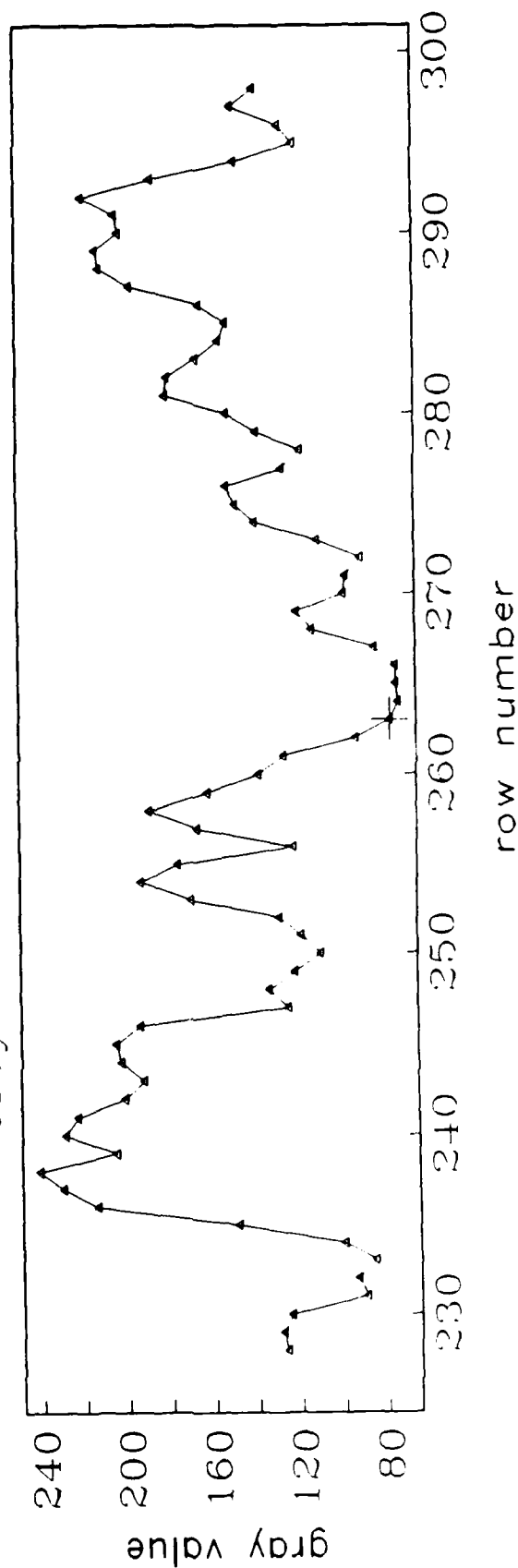
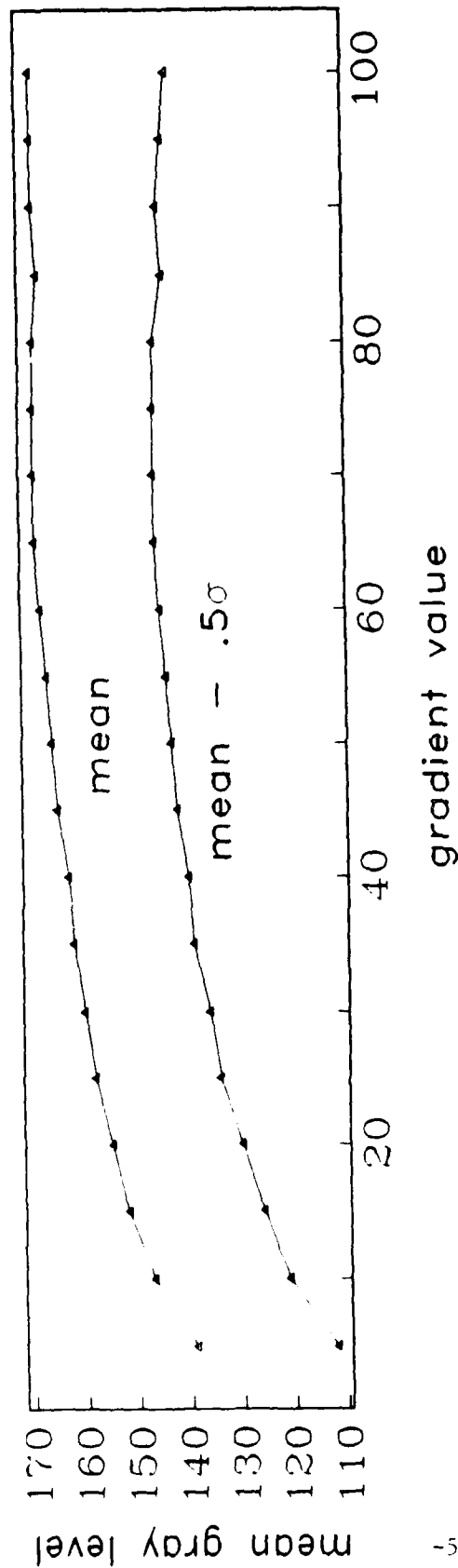


Figure 3 Example of gray value distribution in a row-column test over land

Gran Canary No.3 clouds over water

Mean gray value vs gradient distribution



Cumulative percentage of total gradient

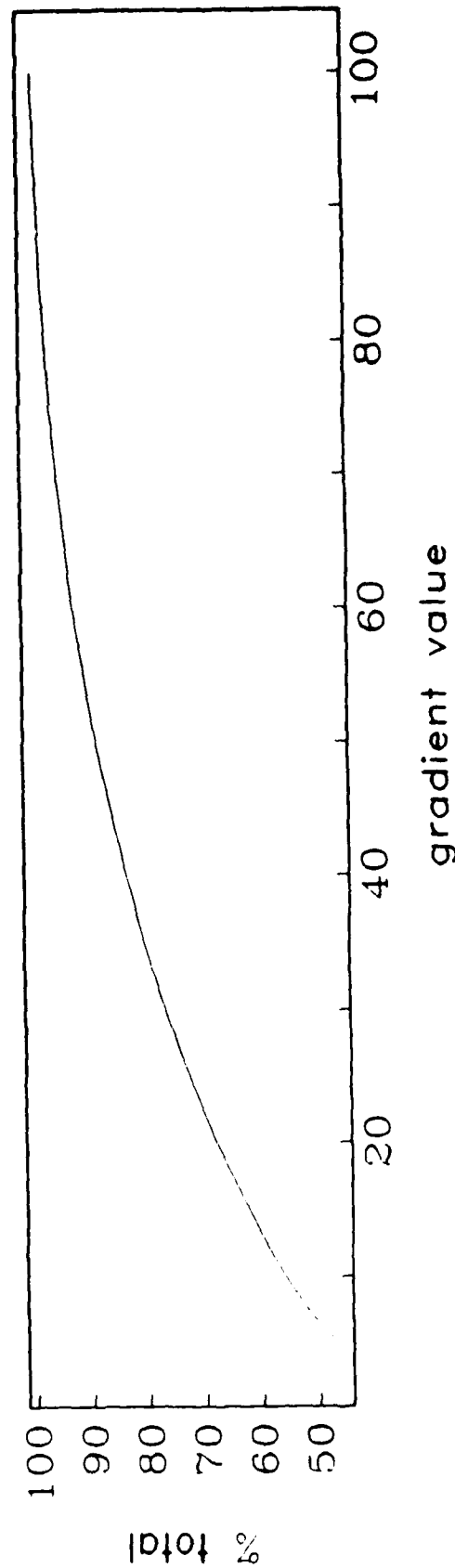
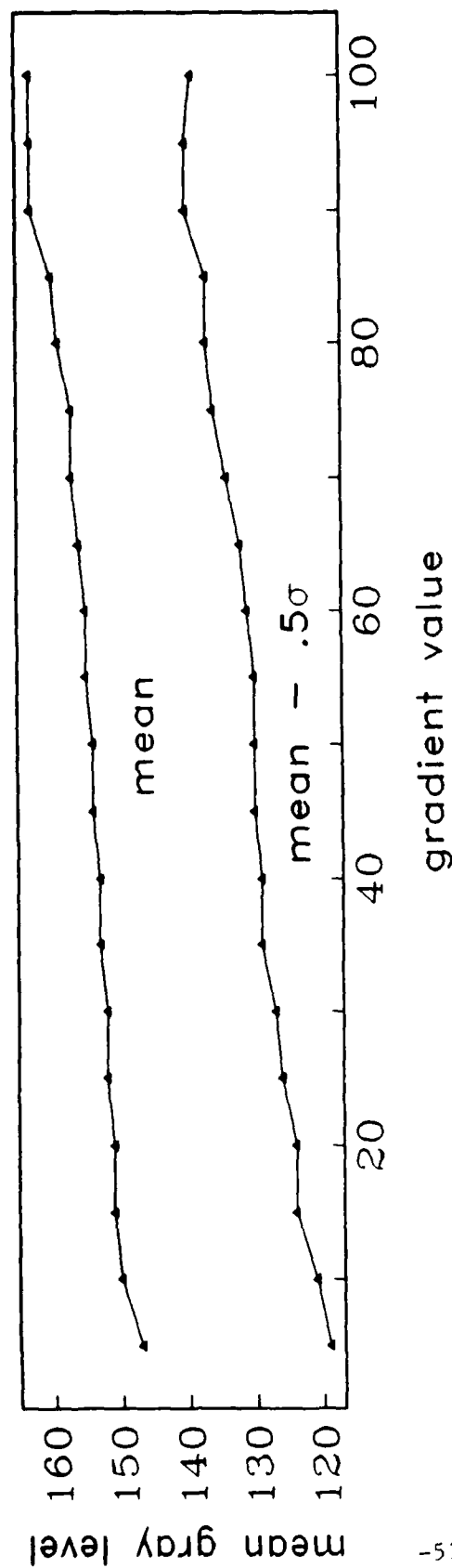


Figure 38 Plots for gradient method approach in over water portion

Gran Canary No.3 clouds over land

Mean gray value vs gradient distribution



-53-

Cumulative percentage of total gradient

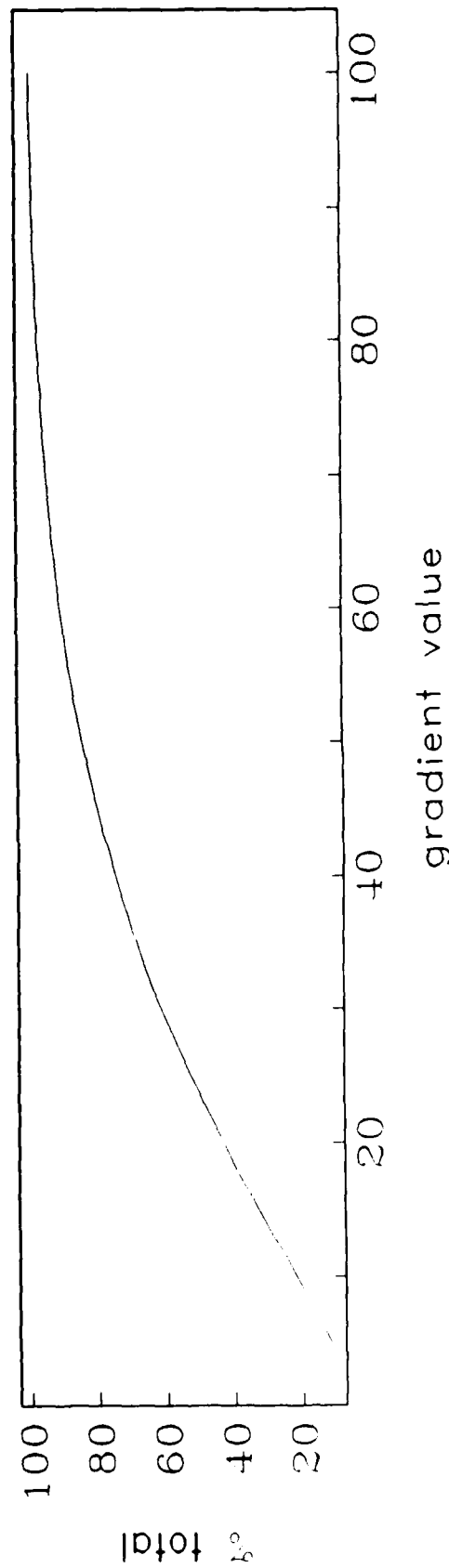


Figure 3 Plots for gradient method approach in over land portion

Variance vs Mean g.l. Gran Canary N0.3 window size 5
Clouds over water

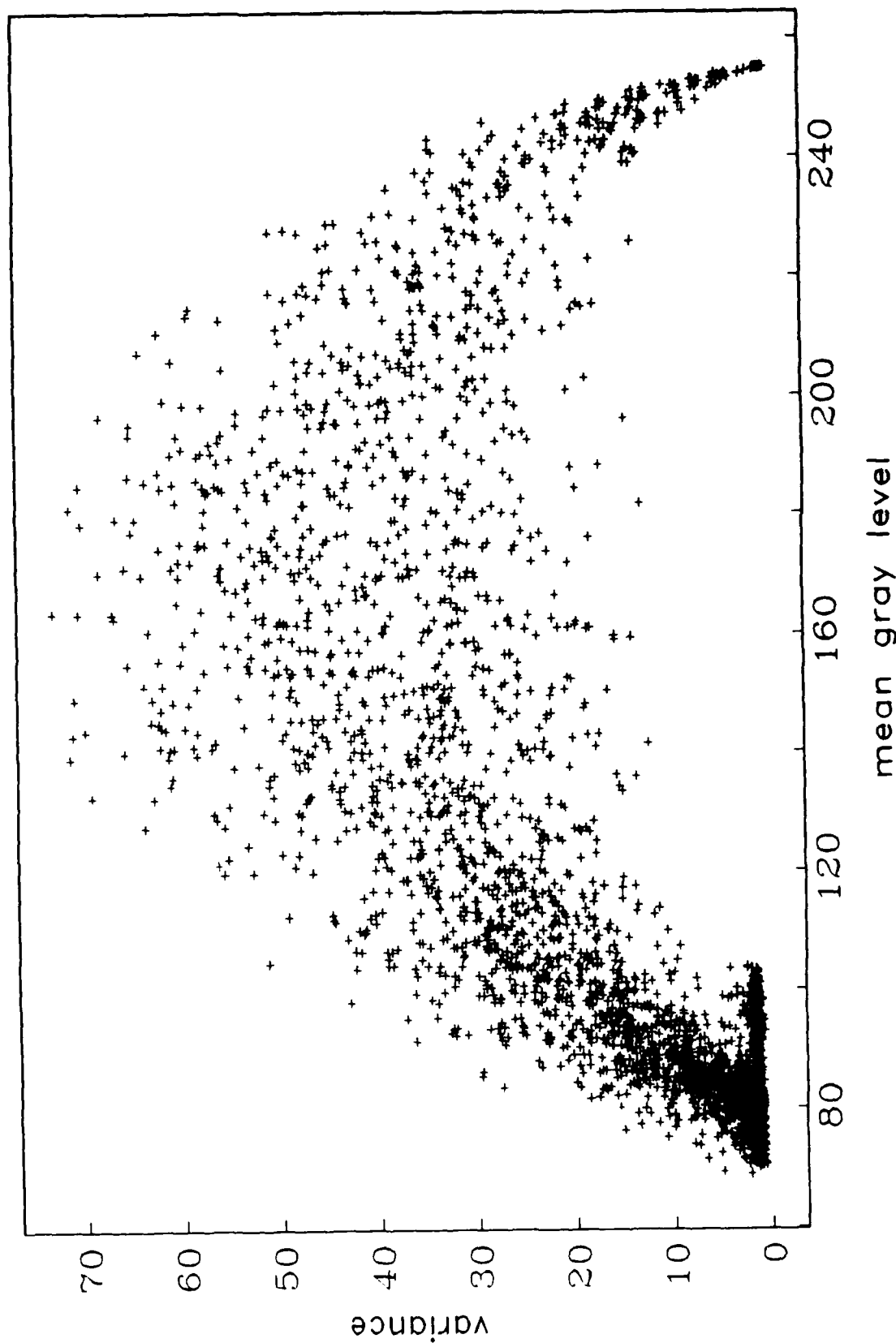


Figure 40 An arch for 5x5 box of horizontal homogeneity method in over water portion

Variance vs Mean g.l. Gran Canary N0.3 window size 7

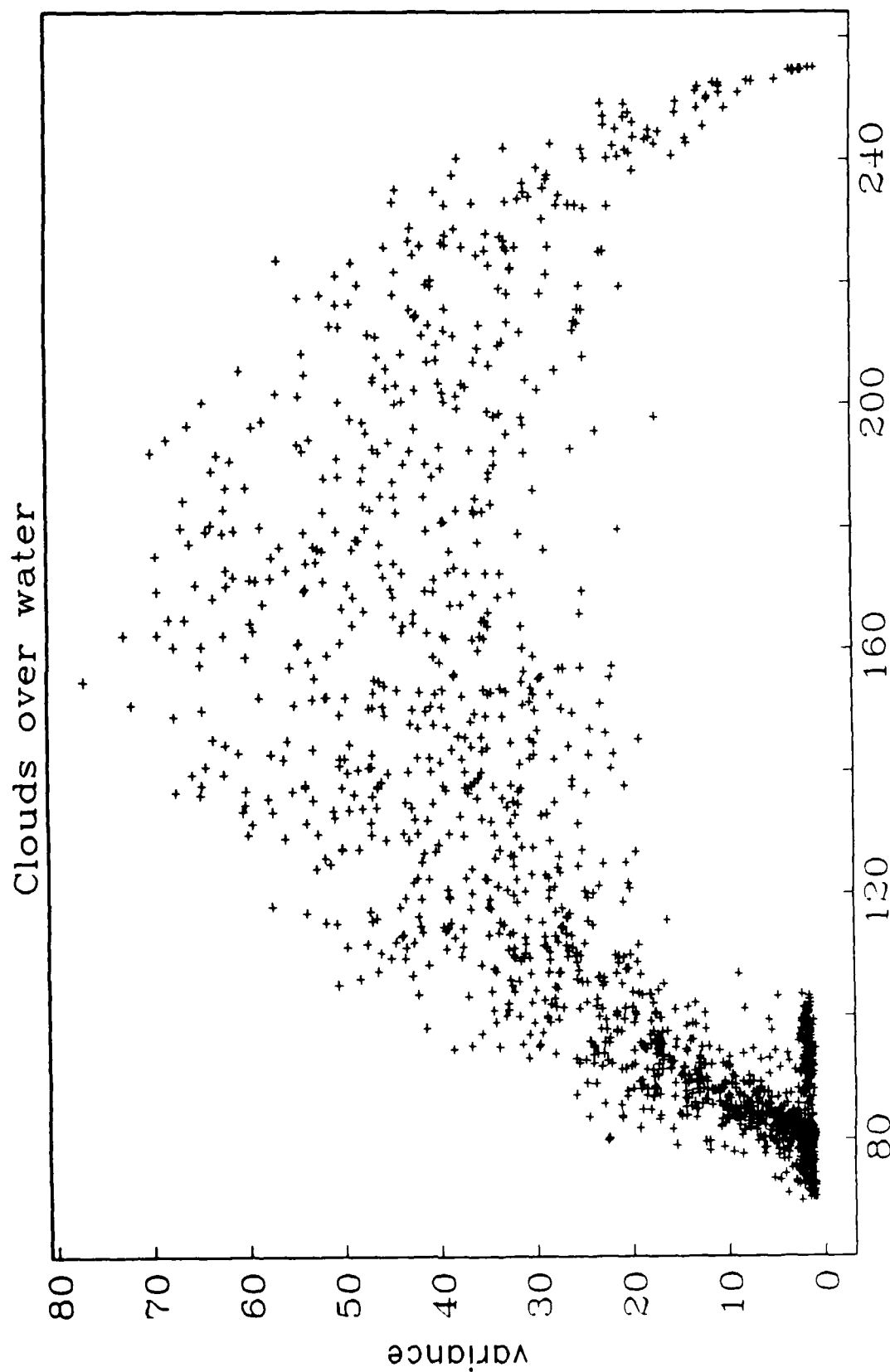


Figure 41 An arch for 7x7 box of horizontal homogeneity method in over water portion

Variance vs Mean g.l. Gran Canary N0.3 window size 5

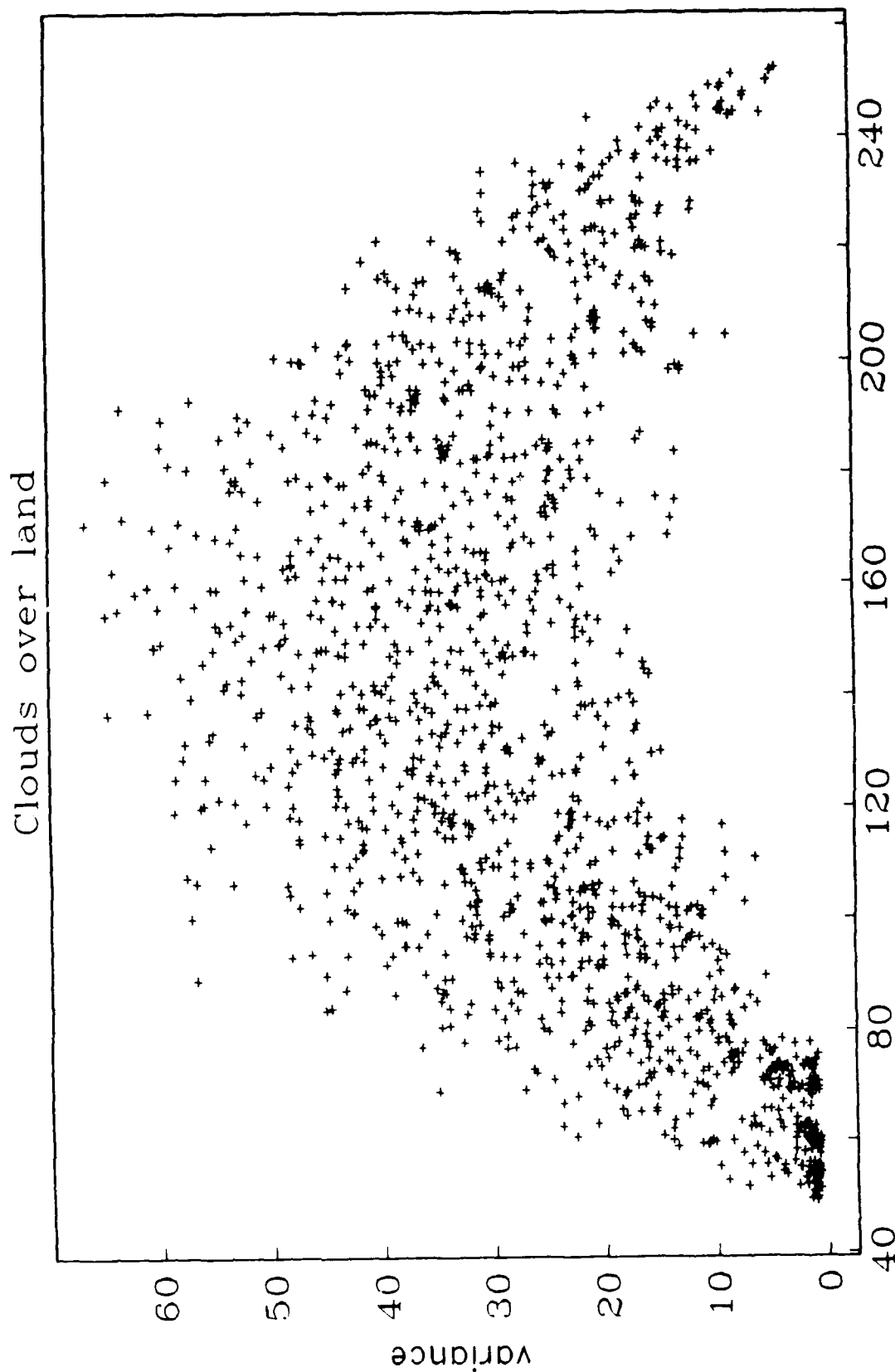


Figure 42 An arch for 5x5 box of horizontal homogeneity method in over land portion

Variance vs Mean g.l. Gran Canary N0.3 window size 7
Clouds over land

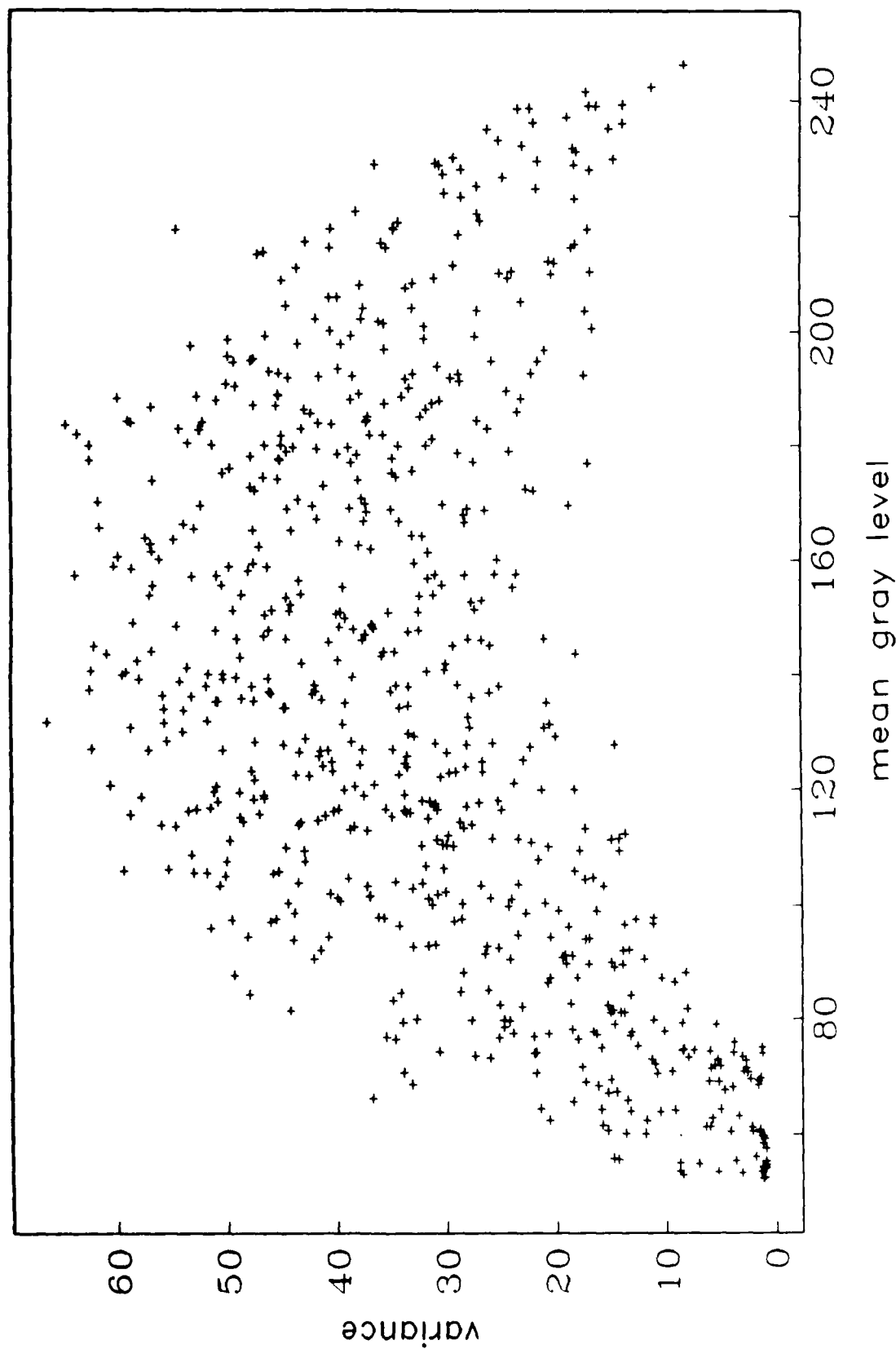


Figure 4 : An arch for 7x7 box of horizontal homogeneity method in over land portion

Gran Canary No.3 over water window size = 5

Histogram of Variance ≤ 5 Mean < 180

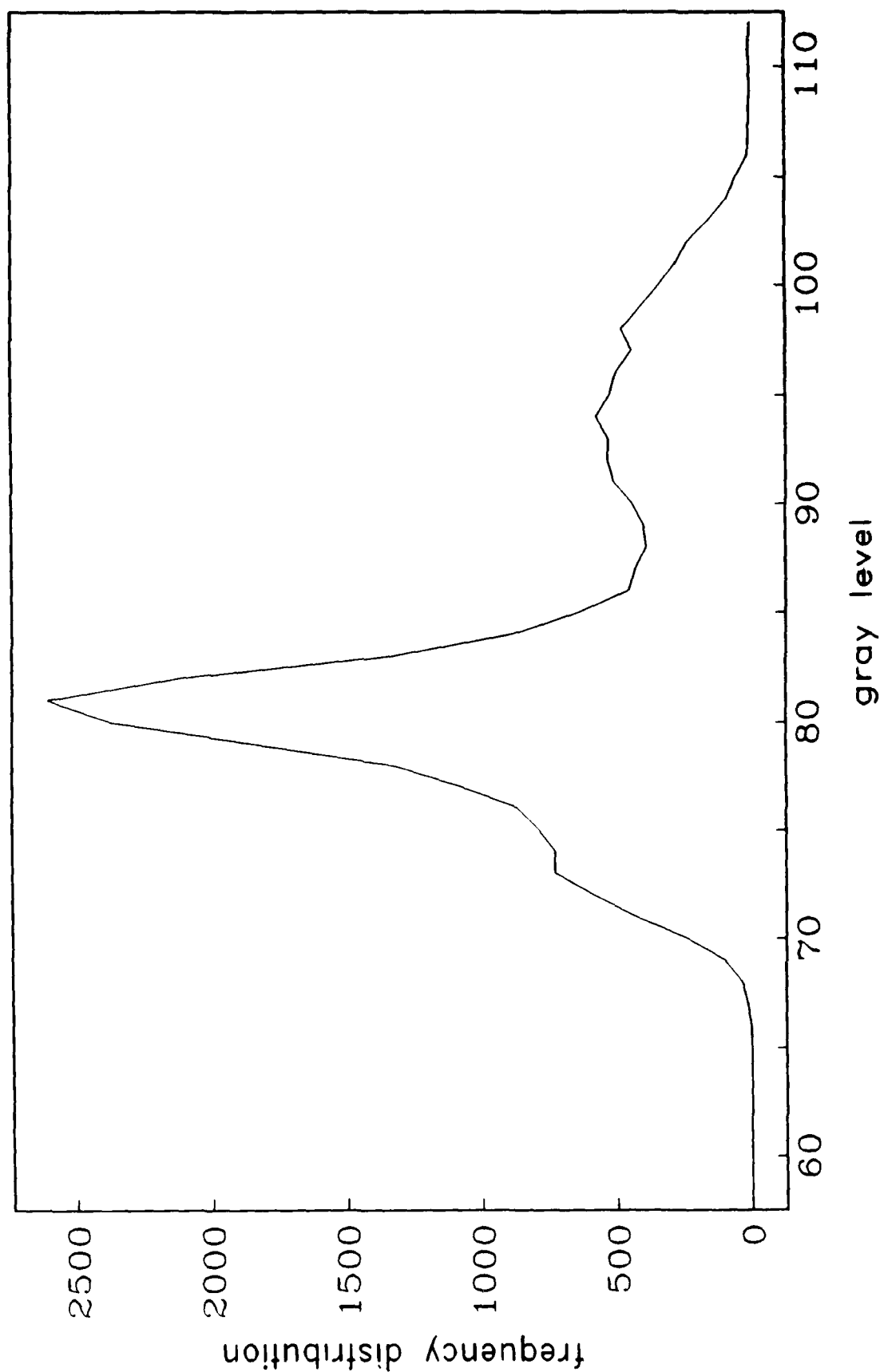


Figure 44 Histogram for the left foot of an arch for a box size 5x5 for the portion over water

Gran Canary No.3 over water window size = 7

Histogram of Variance ≤ 5 Mean < 180

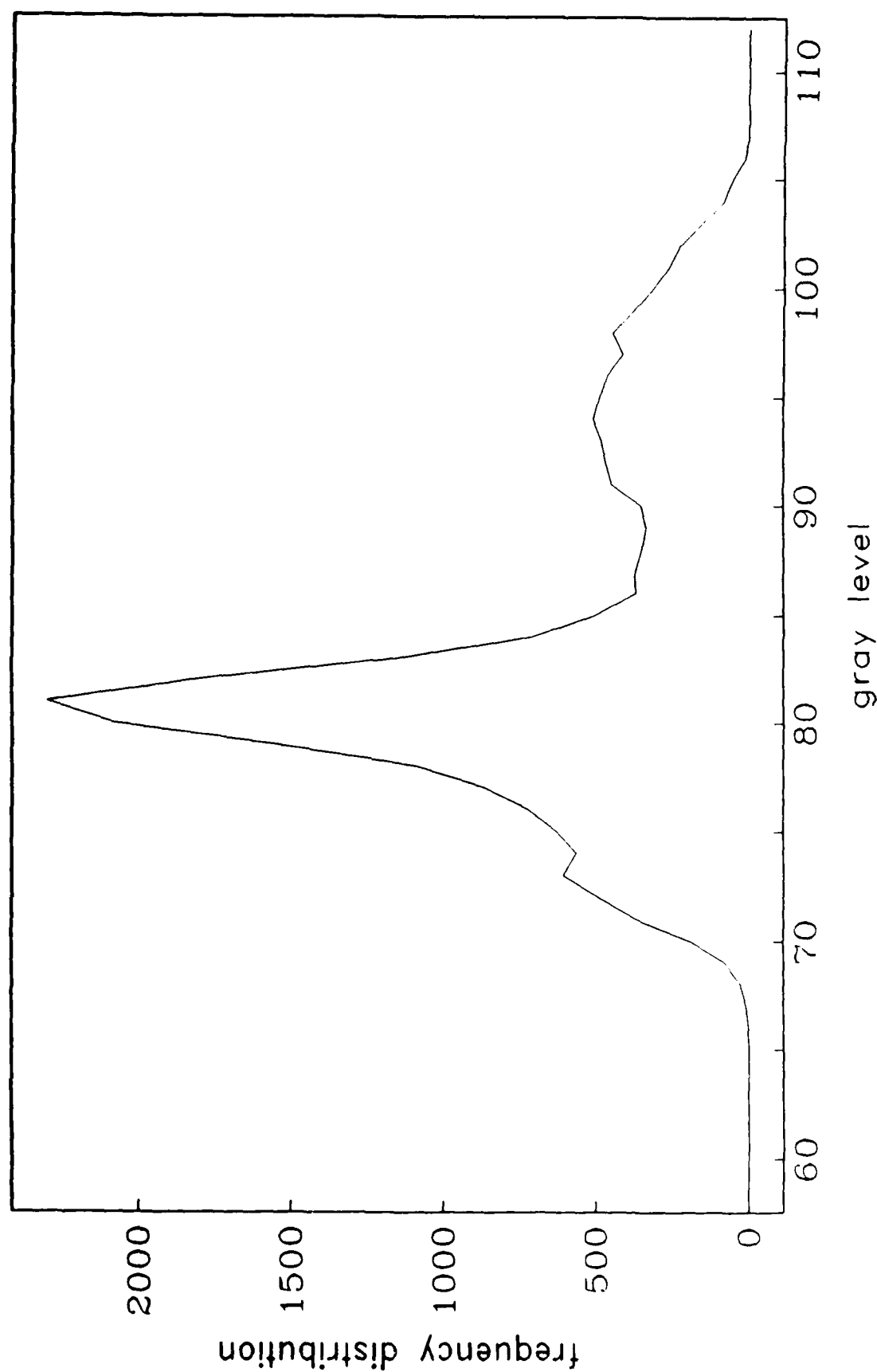


Figure 4: Histogram for the left foot of an arch for a box size 7×7 for the portion over water

Gran Canary No.3 over land window size = 5

Histogram of Variance ≤ 5 Mean < 180

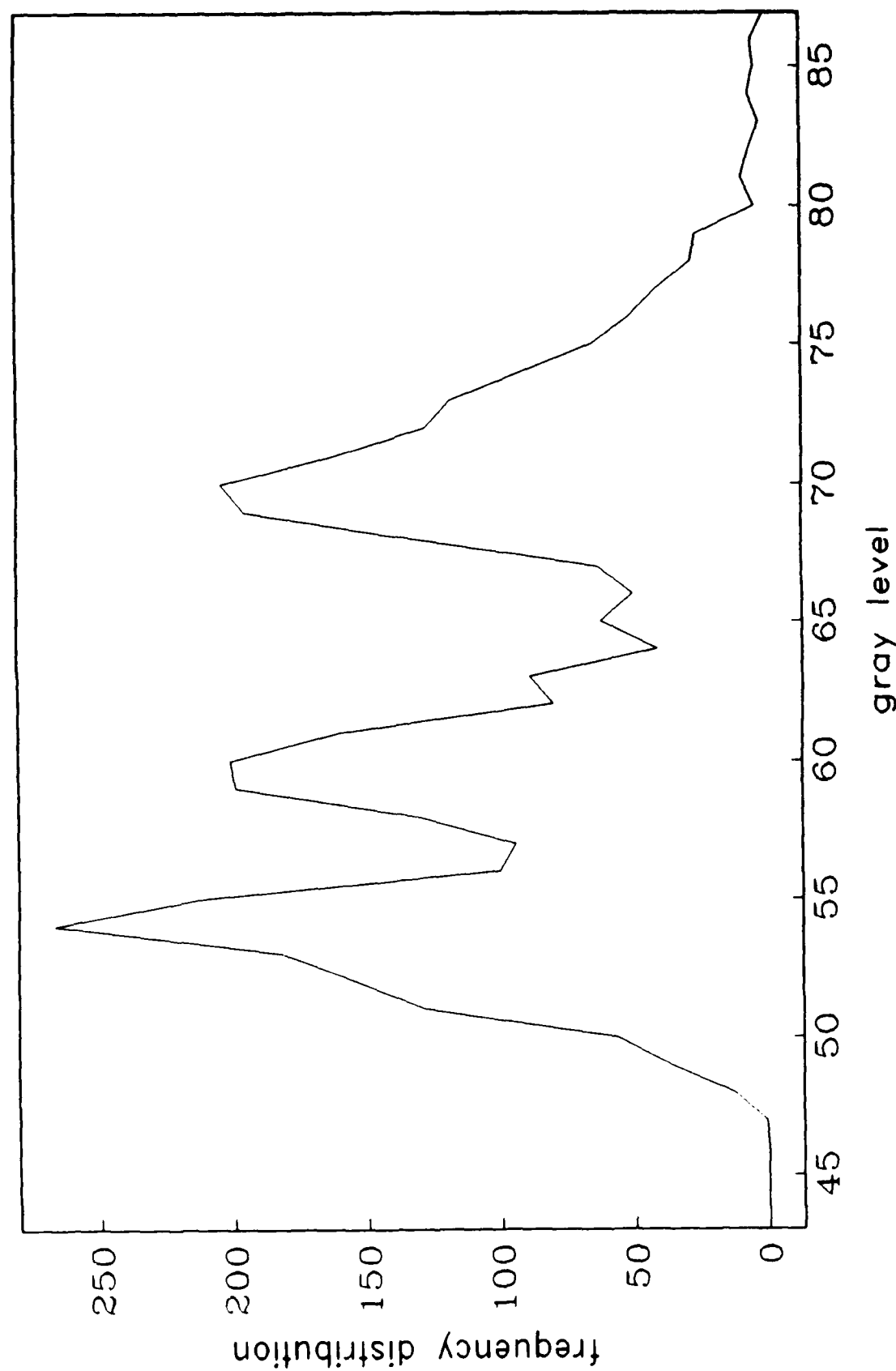


Figure 46 Histogram for the left foot of an arch for a box size 5x5 for the portion over land

Gran Canary No.3 over land window size = 7
 Histogram of Variance ≤ 5 Mean < 180

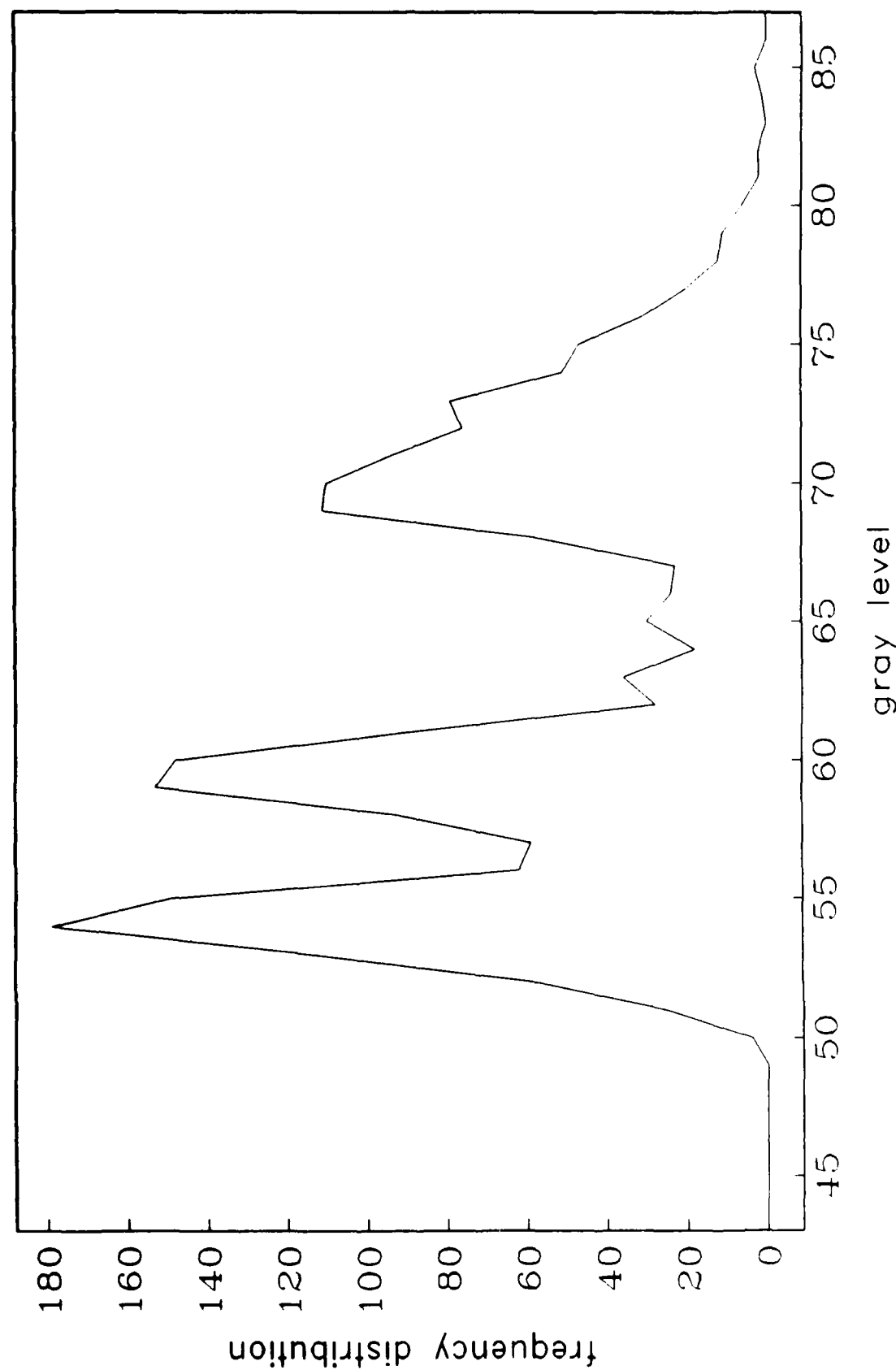


Figure 4 Histogram for the left foot of an arch for a box size 7x7 for the portion over land

APPENDIX C

(FROM THE PHASE I PROPOSAL)

Digitization Principles

The digitization of the shuttle black and white transparencies is to be carried out on an Optronics P-300 scanner connected to the bus of a MicroVAX II. A brief description of the digitization technique used by the Optronics scanner follows.

Rasterization Procedure

Typically, a laser beam is directed along the axis of a lathe-like rotating drum mechanical assembly. A 45° angled mirror redirects the beam at 90° to the axis so that it shines onto the inner surface of the rotating drum. A window in the drum allows the beam to pass out from the drum for some fraction of each revolution. As the beam exits the drum, it impinges onto a light detector, producing an electrical signal. A clear window produces a square wave output signal from the detector as the drum rotates. By inserting a photo transparency over this drum window, the laser beam is caused to scan a line across the photo; thus the signal from the detector is modulated by the variation in photographic density from point to point along this scan line. Opaque points let little light reach the detector, whereas clear points on the photo diminish the light transmission only slightly.

If the drum is allowed to move along the axis very slowly, a raster pattern will be scanned over the entire window, one line per drum rotation. The amount of movement along the axis per drum rotation is chosen to match the beam diameter at the window, and the beam is brought to a focus using a lens assembly with the focal point at the film surface. The analog signal from the detector element is amplified and sampled to break it into pixels, and each sample is quantized by an analog-to-digital computer. The results are transmitted into the computer over a high-speed connection.

Data Encoding

The resolution of the Optronics scanner can vary from 12.5 microns to 500 microns. Thus, for a standard 35mm transparency with an active window of 24mm by 36mm, we have a matrix of 1920 vertical by 2880 horizontal pixel resolution at 12.5 microns resolution. The Optronics P-300 scanner digitizes transparencies into 256 grey levels.

To properly set the black and white window, a large number of training samples is required. When using the scanner on a large batch of film, it is necessary to first scan the entire batch in order to adjust the threshold. Then assuming that each pixel represents

one byte of information, each image is composed of 1920×2880 pixels and is roughly 5.5 megabytes. If such a resolution is not sufficient, then high contrast reproduction of the film is warranted, and, with a resulting slide of 5 by 5 inches, virtually any resolution can be obtained up to 20,000 pixels per scan line (such a resolution is prohibited by the size of the resulting image file, however, which is on the order of 350 megabytes).

The scan file for each image yields a run-length encoded file on the VAX computer. Our experience shows that for temporary storage the run-length encoding greatly saves disk space (up to 50%). An illustration of the process is provided in Appendix A of the present proposal: a sample 35mm color transparency of the shuttle photograph has been digitized at 50 microns resolution, and one-quarter of the resulting image in 256 grey steps (original image size 1400×1400 pixels) is also shown.

Errors

All of the steps in the process of digitization described above involve a certain degree of uncertainty and error. Simply finding the best overall dynamic range of a group of transparencies involves a lengthy procedure of sampling and experimentation. The step involving the change from the analog signal of the laser beam to the sampled digital signal varies in allowed errors, depending on the resolution of the step, thus allowing for a trade-off. There are a number of choices to be made in search of the best combination for scanning, e.g., the problem of scanning an image at too high resolution and coming up with the actual grains of the film instead of meaningful information. Our goal in the Phase I effort and even more so in further work is to develop a knowledge-based system that will govern work with different sets of images and will help to determine automatically the most appropriate techniques and procedures.

END

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